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A study of the acoustical properties of ventilation duct terminal devices

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A STUDY OF THE ACOUSTICAL PROPERTIES OF
VENTILATION DUCT TERMINAL DEVICES

James Edward Kaune
and
Calvin Eugene Rakes

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**A STUDY OF THE ACOUSTICAL PROPERTIES OF
VENTILATION DUCT TERMINAL DEVICES**

by

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B. S., U. S. Naval Academy, 1950

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B. S., U. S. Naval Academy, 1949

**SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF
NAVAL ENGINEER**

**from the
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
1955**

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**Department of Naval Architecture and Marine Engineering
May 23, 1955**

Thesis Supervisor.....

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A STUDY OF THE ACQUISITION OF
TECHNICAL SKILLS

by

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U.S. Naval Academy, 1944

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U.S. Naval Academy, 1944

SUBMITTED IN PARTIAL FULFILLMENT OF THE
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MASTERS IN ENGINEERING

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MASSACHUSETTS INSTITUTE OF TECHNOLOGY
1944

Author.....

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Department of Naval Architecture and Marine Engineering
May 11, 1944

Thesis Supervisor.....

Chairman of Department
Committee on Graduate Studies.....

**A STUDY OF THE ACOUSTICAL PROPERTIES OF
VENTILATION DUCT TERMINAL DEVICES**

by

JAMES EDWARD KAUNE, Lieutenant (junior grade), U.S. Navy

and

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Submitted in partial fulfillment of the requirements for the degree of
Naval Engineer from the Massachusetts Institute of Technology,
May 23, 1955.

ABSTRACT

The purpose of this investigation was to present the results of acoustical measurements on six representative types of ventilation duct terminal devices and determine what characteristics or trends, if any, they might have in common. The acoustical measurements to be made consisted of sound pressure levels in one-third octave bands from 50 cps to 10,000 cps as a function of effective velocity and volumetric rate of flow. Directivity patterns were also taken for typical values of air flow to determine whether the terminal devices were directive to any appreciable degree. From the above data acoustic power level could be calculated.

Three grilles, two registers and one diffuser were tested under various configurations of damper position and air throw.

The test set-up consisted of mounting the test specimen in a large heavy measuring duct. Air is supplied by a centrifugal fan which is acoustically isolated from the measuring duct by means of a sinusoidal muffler. To prevent longitudinal standing waves in the duct, it was coupled via an exponential horn to an anechoic termination. The microphone was shielded by a windscreen and was located downstream from the device under test.

A STUDY OF THE PHYSICAL PROPERTIES OF FERTILIZERS AND IRRIGATIONAL DEVICES

by

LESLIE KENNETH BAKER, Assistant Engineer, U.S. Navy

and

DAVID KENNETH BAKER, Lieutenant, U.S. Navy

Submitted in partial fulfillment of the requirements for the degree of
Master of Science from the Massachusetts Institute of Technology,
May 22, 1922.

ABSTRACT

The purpose of this investigation was to present the results of
experimental measurements on the physical properties of fertilizers
and irrigation devices and determine what characteristics are essential
to make them useful in practice. The experimental measurements
were made on a number of typical fertilizers and irrigation devices
in the form of granules and pellets. The results of the experiments
showed that the physical properties of these materials are of great
importance in determining their behavior in practice. The results
of the experiments are presented in the form of a series of graphs
and tables, and the conclusions are summarized in the following
statements:

1. The physical properties of fertilizers and irrigation devices are of
great importance in determining their behavior in practice.

2. The physical properties of fertilizers and irrigation devices are of
great importance in determining their behavior in practice.

The test data obtained indicated that the directivity of the device was small. The power level in the region tested increased at a rate of about 18 decibels per octave of air velocity. On the other hand, the PWL_{SIL} increased at about 25 per octave of air velocity. It appears that a good parameter for comparing grilles and registers of the same size is the effective velocity. Since the only size of grille and register tested was 10" x 5" it was impossible to say what the effect of size on the PWL and PWL_{SIL} is; however, Stewart and Drake (12) in their empirical equations for loudness include a term containing core area, from which one would infer that acoustic power is also directly proportional to the core area, effective velocity being held a constant. There is no previous data with which these results could be compared.

Further work is necessary in order to obtain more statistical data on other types of diffusers. Also additional work is necessary to ascertain the effect of varying size on the PWL and PWL_{SIL} .

Thesis Supervisor: Leo L. Beranek
 Title: Associate Professor of Communications Engineering

ACKNOWLEDGMENT

The authors are deeply indebted to a number of individuals who made this investigation possible. However, in particular, the constant assistance and valuable suggestions offered by Professor L. L. Beranek, Dr. Ira Dyer, and Mr. G. W. Kamperman were greatly appreciated.

The authors wish to express their gratitude to Bolt Beranek and Newman, Inc., and to the Acoustics Laboratory at MIT for the use of their facilities and equipment.

ACKNOWLEDGMENT

The authors are greatly indebted to a number of individuals who
made this investigation possible. However, in particular, the constant
assistance and valuable suggestions offered by Professor L. J. Berman,
for the last two years of his association were greatly appreciated.

The authors wish to express their gratitude to both parents and
sponsors, Mrs. J. and in the Laboratory Laboratory at MIT for the use of
their facilities and equipment.

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I INTRODUCTION

Until recently the ventilation design engineer had long been handicapped by the lack of adequate data for predicting system noise quantitatively prior to installation and operation of the system. On board ship we find that the primary source of noise outside the machinery space is the ventilation system.

Although considerable effort has been directed along the lines of design of ventilation ducts and plenum chambers for attenuating the noise of the fan, little quantitative investigation of the noise makers themselves had been made.

One of these noise makers, the fan, has recently been investigated and reported in papers before the Acoustical Society. In March 1953, two articles appeared concerning this problem. The first, written by L. L. Beranek, J. L. Reynolds and K. E. Wilson, described the apparatus and procedures for predicting ventilation system noise; the second, by C. F. Peistrup and J. E. Wesler, reported the acoustical measurements taken on five commercially available ventilating fans using the apparatus described in the first paper. In March 1955, a paper by L. L. Beranek, G. W. Kamperman and C. H. Allen was published in The Journal of the Acoustical Society of America on the subject of noise of centrifugal fans. In order to overcome some of the limitations of the previous work, it had covered a larger number of fans over a wider range of horsepower.

1. INTRODUCTION

Until recently the ventilation design engineer has had been handicapped by the lack of adequate data for predicting system noise quantitatively prior to installation and operation of the system. The point was that the primary source of noise within the room, namely space in the ventilation system.

Although considerable effort has been directed along the lines of design of ventilation ducts and plenum chambers for attenuating the noise at the fan, little quantitative investigation of the noise sources themselves has been made.

One of these noise sources, the fan, has recently been investigated and reported in papers before the Acoustical Society. In March 1951, two articles appeared concerning this problem. The first, written by L. L. Bateman, J. L. Stephens and R. H. Wilson, described the apparatus and procedures for predicting ventilation system noise; the second, by C. F. Stephens and J. L. Wilson, reported the experimental measurements taken on five commercially available ventilating fans using the apparatus described in the first paper. In March 1952, a paper by L. L. Bateman, G. W. Knappebaum and C. H. Allen was published in the Journal of the Acoustical Society of America on the subject of noise of mechanical fans. In order to overcome some of the limitations of the previous work, it had covered a larger number of fans over a wider range of parameters.

The Material Laboratory at the New York Naval Shipyard has performed work in the field of ventilation system noise and recently the Bureau of Ships, Department of the Navy, has issued a notice, based in part on the findings of the above mentioned laboratory, setting forth a method for determining noise from ventilation and air conditioning systems for ships.

Very little work has been done in a quantitative way regarding a second noise maker, the terminal device. The earliest reference these writers were able to find regarding a work of this kind was "The Noise Characteristics of Air Supply Outlets," by D. J. Stewart and G. F. Drake, published in the 1937 transactions of the American Society of Heating and Ventilating Engineers. This work did not indicate that any attempt was made to obtain spectrum levels, directivity patterns, or sound power level. Only loudness level in a room of 100 sabins was determined as a function of the air face velocity and the grille core area. Only a long throw type of grille was tested.

Certain manufacturers of air supply outlets do publish small scraps of information giving "A" scale loudness level that may be expected for various ranges of volumetric rates of flow; however, it is not adequate for good design purposes.

It is the purpose of this work to present the results of acoustical measurements on six representative terminal devices. Two registers, three grilles, and one diffuser were tested. The effect of using

The chemical laboratory at the New York Naval Hospital was
 performed work in the field of ventilation system design and especially
 the Bureau of Naval Ordnance, Department of the Navy, has issued a notice
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 they have a number of interesting notes from ventilation and air
 conditioning systems for review.

Very little work has been done in a systematic way regarding
 a general noise problem, the technical details. The earliest reference
 these authors were able to find regarding a noise of this kind was
 "The Noise Characteristics of Air Supply Systems," by D. A. Brown
 and D. F. Fisher, published in the 1917 transactions of the American
 Society of Heating and Ventilating Engineers. This work did not in-
 dicate that any amount was made to obtain accurate levels, direct-
 ly, however, or sound power level. Only indirect level as a sound in
 100 cycles was determined as a function of the air flow velocity and
 the grille noise level. Only a few types of grilles were tested.

Certain manufacturers of air supply outlets do publish small
 books of information giving "A noise index level" that may be
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It is the purpose of this work to present the results of acoustic
 measurements on the representative practical devices. Two regis-
 ters, three grilles, and one diffuser were tested. The effect of using

straight and diverging throw and partial closing of the dampers was investigated. The acoustical measurements consisted of measuring in one-third octaves the band pressure levels in the measuring duct as a function of volumetric rate of flow and effective velocity where appropriate. From these data the overall sound pressure level and the speech interference level over a 2.4 ft^2 area was calculated.

Directivity patterns in three octave bands were obtained for a typical volumetric rate of flow.

The proposed method for obtaining the data consisted basically of measuring the band pressure levels in a large duct inside of which was mounted the device under test. Air was supplied by a centrifugal fan, acoustically isolated from the rest of the system by a sinusoidal muffler. Standing waves in the measuring duct were prevented by coupling it to an anechoic termination via an exponential horn. Volumetric rate of flow was determined by measuring the air velocity upstream from the grille, register or diffuser under test where the air velocity was reasonably uniform all the way across the duct.

There was a common trend noted between all devices tested which, it is believed, may be of value to the designer. Further investigation is necessary in order to determine the effect of varying grille size on its acoustical properties.

weight and diverging from and partly closing of the diaphragm was investigated. The mechanical measurements consisted of measuring in one-third octave the band pressure inside the manometer duct as a function of volumetric rate of flow and static velocity where appropriate. These data and the overall sound pressure level and the speech intelligibility level over a 1/3 octave were calculated.

Intensity patterns in three octave bands were obtained for

a typical volumetric rate of flow.

The oropharynx method for obtaining the data contained therein of measuring the band pressure inside in a large duct inside of which was mounted the device under test. Air was supplied by a constant flow, accurately insulated from the rest of the system by a welded manifold. Standing waves in the connecting duct were prevented by coupling it to an acoustic termination via an acoustical horn. Volumetric rate of flow was determined by measuring the air velocity upstream from the orifice, registered as differential pressure in air velocity was registered upstream all the way across the duct.

There was a constant flow inside between all devices inside which it is believed, may be of value in the design. Further investigation is necessary in order to determine the effect of varying this flow on the mechanical properties.

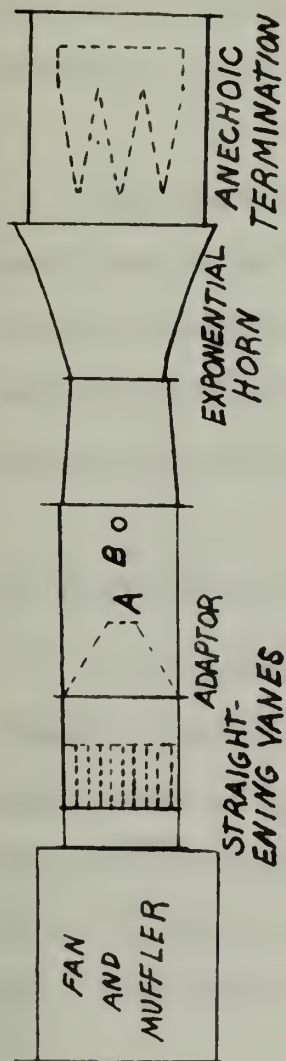
II APPARATUS AND PROCEDURE

Since the reliability, repeatability, accuracy and sense of the data obtained is of paramount importance the apparatus and instrumentation used must yield results which are relatively free from the disturbing influences present when the data was obtained. A complete description of the apparatus and instrumentation is , therefore, considered to be necessary.

A. APPARATUS

The main components used were: a controlable speed fan, a sine wave muffler, a measuring duct, adapters, an anechoic duct termination and a plywood baffle. (See Fig. 1).

The measuring duct was 7 feet long and had a circular cross-section with a $21 \frac{1}{8}$ inch inside diameter. It was constructed with $\frac{1}{16}$ inch galvanized steel and was coated with about $\frac{1}{4}$ inches of Komul (a standard vibration damping mastic). Straightening vanes 1 foot in length were inserted at the muffler connecting end of the duct so that the turbulence would be reduced to a minimum. At the terminal end of the duct there was a square exponential horn which led to the anechoic terminator. The resulting effect of the horn and anechoic termination combination was to effectively eliminate longitudinal standing waves.⁽¹⁾ All flanged sections contained soft rubber gaskets which eliminated air leakage and reduced vibration transmission to a minimum.



A. VENTILATION TERMINAL
DEVICE

B. MICROPHONE OPENING

FIGURE I

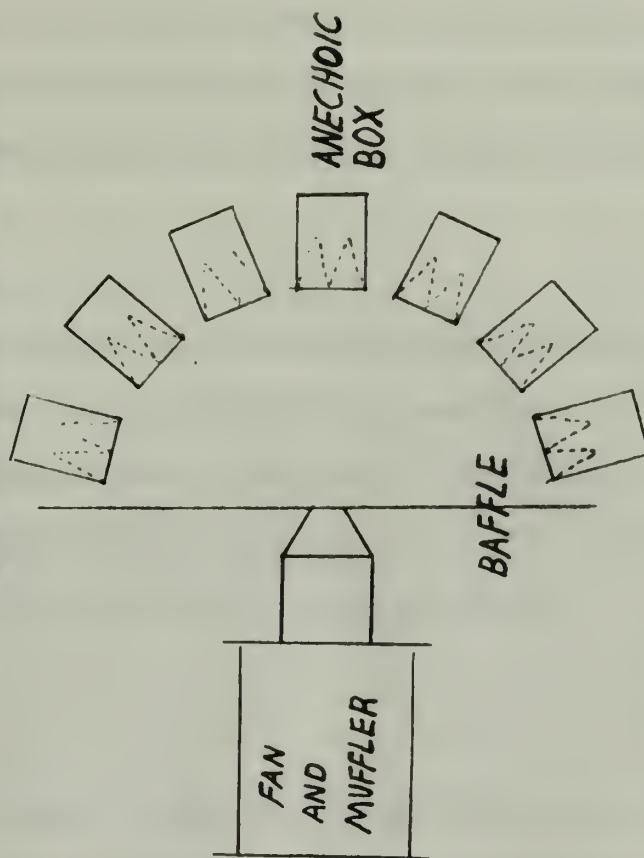


FIGURE II

C&R
JCH
8/10/55



Since a reasonable cross-sectional area of duct to area of grille as well as a sufficient range of air velocities through the grille was desired it was necessary to construct tapered conical adapters. Each was 2 feet long with a $21\frac{1}{8}$ inch diameter at one end but one tapered to a round 8 inch diameter terminal ending while the other tapered to a $9\frac{1}{2}$ inch by $4\frac{1}{2}$ inch rectangular terminal ending. This made possible the testing of rectangular as well as round ventilation terminal devices.

In order to check the directivity pattern of the ventilation terminal devices the measuring duct was removed and a baffle erected at the terminating end of the adapters. (See Fig. 2). Free field conditions were simulated by surrounding the baffle by a semicircle of anechoic boxes and by covering the floor with acoustical blanket.

B. INSTRUMENTATION

The instruments used were: a low velocity air meter (thermocouple), a pitot tube, a manometer, an Altec-Lansing 21-BR-200 microphone, an Altec-Lansing power supply unit type P -525-A, a Magnecorder (amplifier) type PT6-J, a GR SPL meter type 51-A (20 kc scale), a $1/3$ octave band analyzer, a transistor oscillator calibrator and a windscreen.

Since pitot tube measurements at the low velocities found in this experiment are questionable, it was decided that the use of a thermocouple low velocity meter would give more accurate results. Calibration of the air-meter was achieved by using higher velocities and a standard pitot tube.

Since a reasonable time-velocity was to be used in the

as well as a sufficient range of air velocities through the grille was
 desired it was necessary to construct several different types. Each
 was a foot long with a $1\frac{1}{2}$ inch diameter at one end and one tapered
 to a point 4 inch diameter at the other end. The other tapered to
 a $1\frac{1}{2}$ inch by $1\frac{1}{2}$ inch square at the other end. This made pos-
 sible the testing of rectangular as well as round ventilation terminal
 devices.

In order to obtain the necessary range of the velocities in-
 volved in the testing the terminal that was covered and a bottle was used
 as the terminating end of the duct. The 24 inch duct con-
 ducts were simulated by surrounding the bottle by a number of air
 ducts and by covering the flow with a number of air

II. DISTRIBUTION

The distribution of air was a low velocity air supply (approx-
 imately 100 ft/min) at 100 ft/min, as shown in Fig. 1-100
 and 1-100. An air supply unit (type 1-100) was
 connected to the supply unit (type 1-100) by a 24 inch duct (type 1-100)
 and a 1/2 inch duct (type 1-100). A 1/2 inch duct (type 1-100)
 and a 1/2 inch duct (type 1-100).

Since the air velocity in the low velocity duct is low
 experiment was made. It was decided that the use of a duct
 would be better than the use of a duct. The duct
 was of the air duct was made by using a duct and a
 standard type duct.

The Altec-Lansing 21-BR-200 microphone not only has an extremely flat response over the range of frequencies tested, 20 to 10,000 cps, but also has a small physical size which makes windscreen design simpler and results in a windscreen of small dimensions. The overall result is that there is very little error in measurement caused by the microphone response and the physical size of the microphone and windscreen combination assures minimum interference of the sound field inside the duct.

The windscreen was 5 inches long and had a diameter of 3 inches. It was constructed with wire mesh having $1/4$ inch squares covered by standard parachute nylon. Windscreen self noise and sensitivity response corrections were made where applicable.

The Magnecorder was used as the signal amplifier because of its excellent response characteristics over the range of frequencies tested. It has a flat response from 20 to 40,000 cps which more than covers the range of interest for this investigation.

The one-third octave band filter was introduced into the system before the GR SPL meter so that a maximum number of frequency bands could be analyzed. Since the Telefon filter has sharply defined pass bands, corrections for this instrument are quite easily applied.

The GR SPL meter (20 kc scale) also has an extremely flat response over the range of interest.

The microphone was calibrated to read absolute sound pressure level relative to 0.0002 microbar and this reference level was used throughout this investigation.

It was felt that the accuracy of the readings taken depended entirely upon the accuracy of the reader and not upon the instruments themselves. It is believed that with all corrections applied the accuracy of the instruments should fall within a ± 1 db range whereas the best estimate of the accuracy of the reader is about ± 2 db in lower bands to ± 1 db in the higher bands.

C. PROCEDURE

In order to insure that the data obtained were valid many considerations had to be taken in account. They fell roughly into the following categories: directivity, instrumentation crosschecks, repeatability, and instrumentation corrections.

Directivity pattern calculations not only dictated the microphone location and the number of locations necessary for good data, but also served as a check on the PWL's calculated using the measuring duct apparatus. Since the ventilation terminals tested proved to have reasonably non-directive characteristics at the microphone distances used and since wall effects are noted when microphones are placed relatively close to flat or closed surfaces, it was concluded that a center position location of the microphone would prove to be most satisfactory. The results and PWL checks obtained would tend to substantiate this con-

The microphones were calibrated in water according to the standard level values of 0.001 m/sec and then reference level was used throughout the investigation.

It was found that the accuracy of the 1/4-in. dia. tubes deposited directly from the accuracy of the factory and not from the manufacturer. It is believed that with all microphones against the top of the instrument should not with ± 1 dB range whereas the best accuracy of the accuracy of the range is about ± 1 dB or lower. Leads to ± 1 dB in the highest range.

C. PROCEDURE

In order to insure that the data obtained were valid, each microphone had to be tested in a known field. They were roughly into the following categories: directly, instrumentation, response, blind, and instrumentation response.

Consistency between calculations not only showed the microphones location and the number of locations necessary for good data. But also arrived at a check on the TWT's calibration using the constant that appeared. Since the variation between the two was not more than 10% and the difference characteristics of the microphone showed that the microphone was well suited when microphones are placed relatively close to that of sound sources. It was concluded that a better position location of the microphones would prove to be more satisfactory. The results and TWT results showed that with no calculation the con-

clusion. All readings in this investigation are, therefore, centerline readings.

The instrumentation used in this investigation was cross-checked with a set-up containing a GR SPL meter type 1551 with its regular GR crystal microphone and the GR octave band analyzer type 1550. A noise generator (white noise) was used as the sound source. When the 21-BR-200 and the crystal microphones were located at approximately the same point the octave band readings correlated to within ± 2 db which was considered to be satisfactory.

Several complete reruns of tests run approximately one month earlier were made and the correlation was within ± 2 db. This would indicate that repeatability was within reason and should cause no particular concern.

Since self-noise of the windscreen could have an appreciable effect upon the readings taken, self-noise curves of the same type and construction windscreen as that used in this investigation were obtained from Bolt Beranek and Newman, Inc., Acoustical Consultants. They showed that self-noise had a negligible effect on the data taken. However, since the sensitivity of the microphone is reduced because of the presence of the windscreen a correction curve for this effect was made and the appropriate correction was applied to the data recorded.

Since it was the objective of this investigation to see what effects ventilation terminal devices had on terminal openings it was clearly

condition. All readings in this investigation are, therefore, corrected for temperature.

The distribution used in this investigation was curve-fitted with a set-up consisting a 400 Hz. mixer (type 155) with its regular 200 Hz. output, and the 400 Hz. output was attenuated from 100% to 10% (the 400 Hz. output) and used as the sound source. When the 400 Hz. and the 200 Hz. outputs were located at approximately the same point the curve-fitted readings were within ± 1 in which was considered to be satisfactory.

Several separate series of tests are approximately the same relative were made and the correlation was within ± 1 in. This would indicate that reproducibility was within 1% and should cause no further concern.

Since the results of the wind-tunnel tests have an approximate error of 1% when the readings taken, self-sound source of the same type and condition, wind-tunnel as that used in this investigation were obtained from the Bureau of Standards, Inc., (Bureau of Standards, Inc.) showed that self-sound had a negligible effect on the data. However, since the sensitivity of the microphone is reduced because of the presence of the wind-tunnel a correction must be made for this effect was made and the approximate correction was applied to the data recorded.

Since it was the objective of this investigation to see what effect ventilation system had on the sound it was clearly

necessary to obtain the noise of the terminal opening alone with no grille attached. This was done.

showing to him a list of the various objects that he

...and now, I am going to ...

III DEFINITION OF SYMBOLS AND QUANTITIES

A few of the symbols used herein may not normally be found in any standard textbook on acoustics. Some are useful only in this particular investigation; others are used by ventilation engineers. For the sake of clarity, all symbols used will be listed giving their meaning, and, where appropriate, their definitions.

A_c = core area of a register or a grille. This is the area of the hole which would result if grating or fins were removed. Usually the core dimensions are one-half inch shorter on each dimension than the nominal grille size. For example, the size used in this investigation was 10" x 5". The core dimensions were therefore 9 1/2" x 4 1/2", giving a core area of 0.297 ft².

A_e = effective area of a register or grille. For the grilles and registers with dampers fully open, it was taken to be the core area less the projected area of the grating or fins into the plane of the face of the grille. For the register with partially closed dampers, the effective area was taken as the core area less the projected area of the dampers. The effective area to core area ratio varied from .75 to .82 for straight throw grilles. A value of .62 was obtained for diverging throw.

A_n = neck area of the diffuser.

III. THE EFFECT OF TEMPERATURE ON THE GROWTH OF PLANTS

A law of the growth of plants has been found which is valid for all plants and for all parts of the plant. This law is that the rate of growth is proportional to the temperature of the plant. This law is valid for all plants and for all parts of the plant. This law is valid for all plants and for all parts of the plant.

A_p = rate of growth of a plant at a given temperature. This is the rate of growth of a plant at a given temperature. This is the rate of growth of a plant at a given temperature. This is the rate of growth of a plant at a given temperature. This is the rate of growth of a plant at a given temperature.

A_p = effective rate of a plant at a given temperature. This is the rate of growth of a plant at a given temperature. This is the rate of growth of a plant at a given temperature. This is the rate of growth of a plant at a given temperature. This is the rate of growth of a plant at a given temperature.

A_p = rate of growth of a plant at a given temperature.

PWL = acoustic power level measured in decibels re- 10^{-13} watt, i.e., $PWL = 10 \log_{10} \frac{W}{10^{-13}}$ where W = acoustical watts radiated by the source.

PWL_c = acoustic power level per unit of core area, re = 10^{-13} watt/ft². $PWL_c = PWL - 10 \log_{10} A_c$.

PWL_{SIL} = an "acoustic power level" based on speech interference level criterion. The quantity was determined in this manner: the SIL was determined in the usual manner (see definition of SIL following) at the point in the measuring duct where the microphone was located. To this value was added $10 \log_{10} S$, S being the area of the duct in ft² at that point.

$(PWL_{SIL})_c$ = an "acoustic power level" per unit core area based on speech interference level criterion. $(PWL_{SIL})_c = PWL_{SIL} - 10 \log_{10} A_c$. It is intended that this quantity will enable the designer to predict the SIL in a given space if the space acoustic parameters, volumetric rate gain flow and core area are known.

p' = static air pressure in 21" duct upstream from device under test. Pressure is measured in inches of water.

p = pressure drop in inches of water across the device under test. This value was calculated by the following equation:

$$p = p' - \frac{1}{2} \rho (V_2^2 - V_1^2) 0.192$$

where ρ is air density in slugs/ft³, V_1 is velocity in 21" duct. V_2 is velocity immediately upstream of the device under investigation. Both are measured in ft/sec. The constant 0.192 is for converting pounds per square foot into inches of water. The velocity V_1 was measured by means of a thermocouple type air meter.

Q = volumetric rate of air flow in ft.³/min.

SPL = sound pressure level. $re = 0.0002$ dyne/cm². As used in this report it refers to the measured sound pressure level in one-third octave bands in the measuring duct.

SIL = speech interference level. Although speech interference level is defined as the arithmetic average of the SPL's in the octave bands 600-1200, 1200-2400, and 2400-4800, the computed SIL's in this investigation do not correspond exactly because of the particular one-third octave band filter used. The closest approach that could be made was to use the arithmetic average of the SPL's in octave bands 568-1136, 1136-2272, and 2272-4544. Thus octave band 568-1136 includes one-third octave bands 12, 13 and 14; octave band 1136-2272 includes one-third octave bands 15, 16 and 17; and octave band 2272-4544 includes one-third octave bands 18, 19 and 20. This difference is believed not to be important.

S = cross-sectional area of measuring duct at the microphone position in ft.².

V = effective velocity of air through grille or register. It is defined by the equation:

$$V = Q/A_e$$

V_n = neck velocity in the diffuser.

V_{mike} = local velocity measured at microphone position.

γ = effective viscosity of air in the region of interest. It is the

used by the experiment

$$\gamma = \frac{1}{2} \rho V^2$$

γ_0 = local velocity in the diffuse

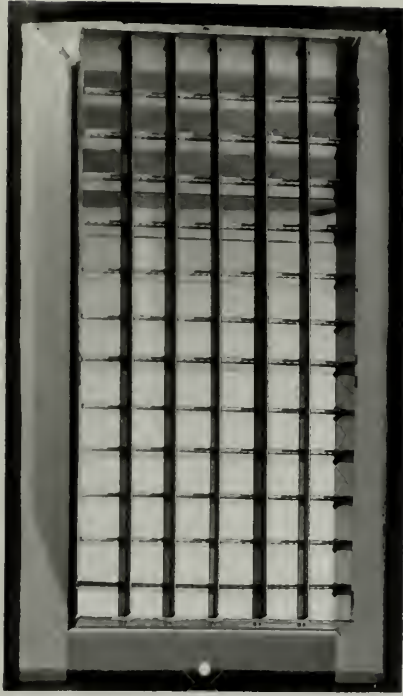
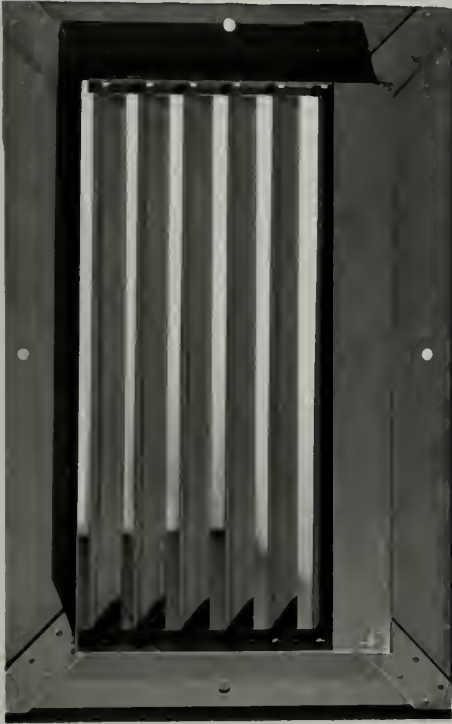
γ_{min} = local velocity measured at minimum position



A B
C D



PLATE I
FRONT SIDE
A-DO C-DOV
B-DV D-TROV



A B

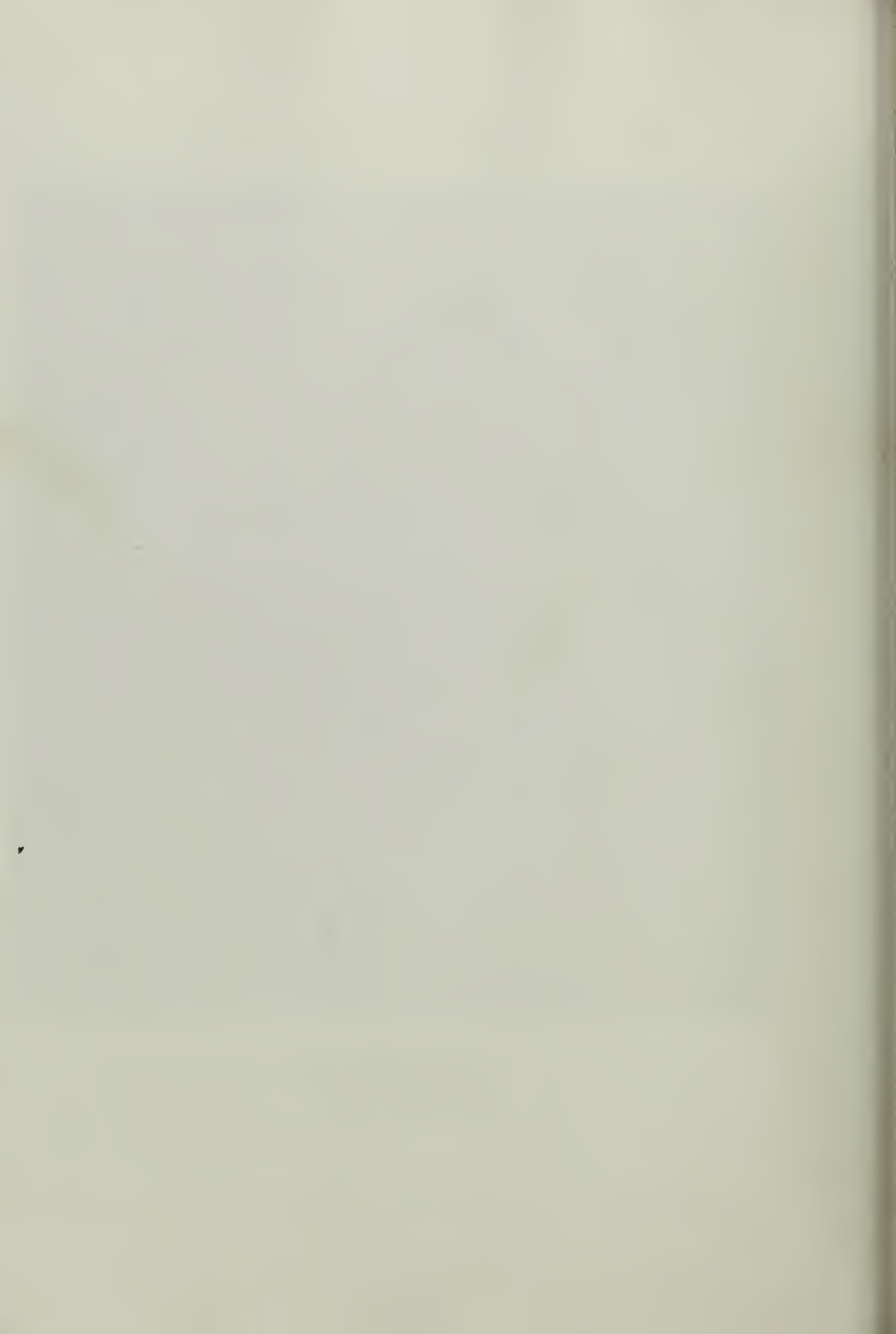
C D



PLATE II
BACK SIDE
A-DO C-DOV
B-DV D-TROV



PLATE III
BAFFLE AND SIMULATED
FREE FIELD SYSTEM



IV CONFIGURATIONS TESTED

Three grilles,* two registers* and one diffuser** were tested. (See Plates I through III.) The grille designated type 188 was stamped from 14 gauge material with 13/16" square hole with 3/16" frets. It is a straight throw type grille. Grille type DO has horizontal fixed face fins set at an angle of 45°. Type DV is a double deflection, double band type grille. The face fins are vertical, the rear fins are horizontal and can be adjusted for either straight or diverging throw. It was tested in both the straight and diverging throw positions.

Type TROV register is the same as grille type DV in so far as fins are concerned. The only difference is in the addition of dampers. Register type DOV is single deflection with vertical face fins which are adjustable to give straight or diverging throw. Type TROV was tested in the straight and diverging throw positions for two damper positions, one position being full open and the other in such a position to give an effective area to core area ratio of 1/2 as defined in Chapter III. The same configurations were tested on the DOV except that a value of 1/3 was selected instead of 1/2 for the effective area to core area ratio. Thus a total of four configurations was tested for each register.

The diffuser tested is an adjustable air supply outlet consisting of four cones. The inner three cones are attached to the outer cone by

* For registers and diffusers, see General Register Catalog No. 101A, 1954.

** See Anemostat Selection Manual No. 50, 1955, diffuser type C-22.

IV. COMBINATION TESTS

Three grilles, * two registers, and one diffuser ** were tested. (See Plates I through III.) The grille designated type I was made from 14 gauge material with $13\frac{1}{16}$ " square hole with $\frac{3}{16}$ " hole. It is a straight throw type grille. Grille type II has a horizontal face line set at an angle of 45° . Type III is a double deflection, double bend type grille. The face line is vertical, the rear line is horizontal and can be adjusted for either straight or diverging throw. It was tested in both the straight and diverging throw positions.

Type TROV register is the same as grille type IV in an air flow line are concerned. The only difference is in the addition of dampers. Register type DOV is single deflection with vertical face line which are adjustable to give straight or diverging throw. Type TROV was tested in the straight and diverging throw position for two damper positions, one position being full open and the other in such a position to give an effective area to core area ratio of $1/2$ as defined in Chapter III. The same configurations were tested on the DOV except that a ratio of $1/3$ was selected instead of $1/2$ for the effective area to core area ratio. Thus a total of four configurations was tested for each register.

The diffuser tested is an adjustable air supply outlet consisting of four cones. The inner three cones are attached to the outer cone by

* For registers and diffusers, see General Register Catalog No. 101A, 1954.
 ** See Anemostat Selection Manual No. 20, 1955, diffuser type C-2.

means of a central bridge. By rotating the innermost cone the air distribution can be varied from a horizontal pattern to a direct downward discharge. Two configurations were tested, one with the cones set for the horizontal air pattern and the other for the direct downward discharge through XXXIV. The center load frequencies of the sea-lard water charge.

load filter are given in Appendix 2.

FIG. 11. Data supplied through the monitoring of the primary air system. Int. 14 Unit 1, Cambridge, Mass. See Fig. 11 of the Appendix.

The horizontal air scatterer and the other for the direct dispersion die-

dielectricity. Two configurations were tested, one with the point gap for

reflection can be varied from a horizontal position to a direct downward

position of a vertical helix. By rotating the horizontal plate the air die-

V RESULTS

The results of this investigation are embodied in Figures III through XXXVII. The center band frequencies of the one-third octave band filter are given in Appendix B.

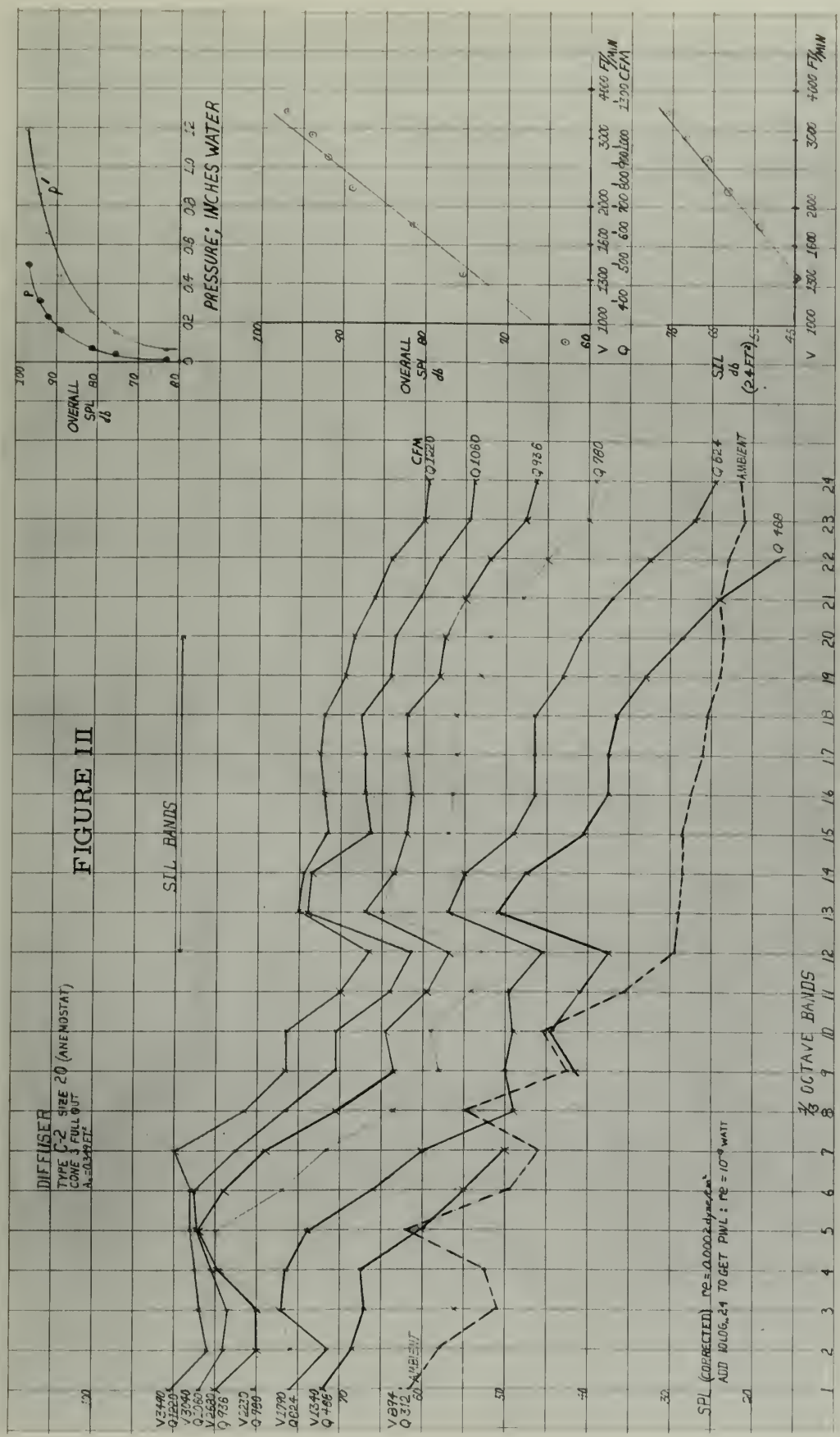
Note 1: Data supplied through the courtesy of Bolt Beranek and Newman, Inc., 16 Elliot Street, Cambridge, Mass. See Fig. A-1 of the Appendix.

16

V. RESULTS

The results of this investigation are included in Figures 11 through XXVII. The same data (averages of the one-third corner band filter are given in Appendix B).

Note: Data supplied through the courtesy of Bell Telephone and Telegraph Inc., 18 Main Street, Cambridge, Mass. See Fig. A-1 of the Appendix.



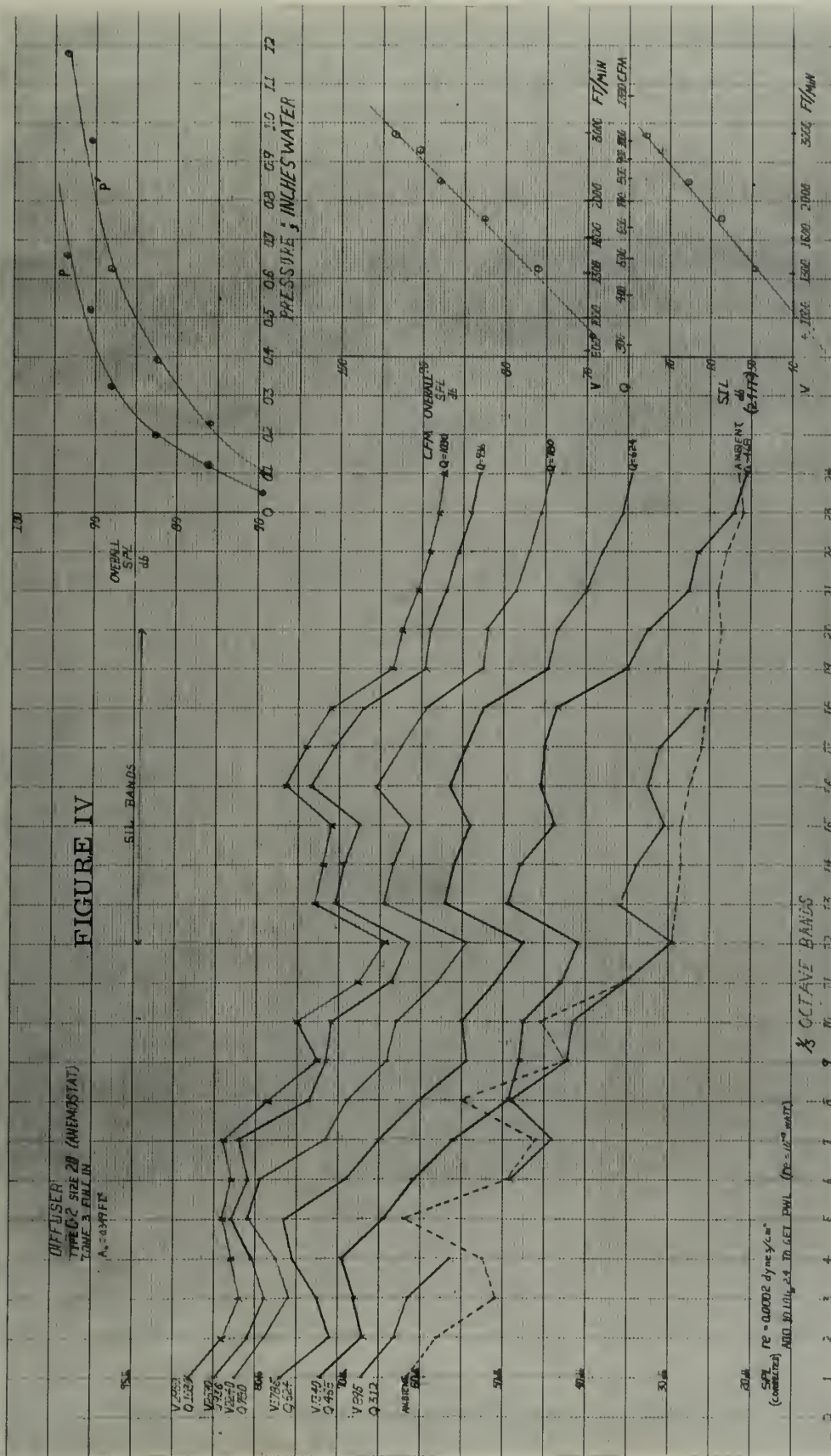


FIGURE V

GRILLE
TYPE IV SIZE 10" x 5"
STRAIGHT THROW
A₀ = 0.245 FT²

V1770
Q1170

V4450
Q1090

V3500
Q3500

V2870
Q565

V1910
Q760

V1630
Q374

V1150
Q281

50 dBA

AMBIENT

40 dBA

30 dBA

SPL CORRECTED RE = 10000 dynes/cm²
ADD 10 LOG 2.4 TO GET P.W. RE = 10⁻¹ WATT

20 dBA

1/3 OCTAVE BANDS

1/3 OCTAVE BANDS

PRESSURE, INCHES WATER

V 1000 1200 1400 1600 1800 2000 2200 2400 2600 2800 3000 3200 3400 3600 3800 4000 4200 4400 4600 4800 5000 FPM
Q 300 400 500 600 700 800 900 1000 1100 1200 CFM

V 1000 1200 1400 1600 1800 2000 2200 2400 2600 2800 3000 3200 3400 3600 3800 4000 4200 4400 4600 4800 5000 FPM
Q 300 400 500 600 700 800 900 1000 1100 1200 CFM

FIGURE VI

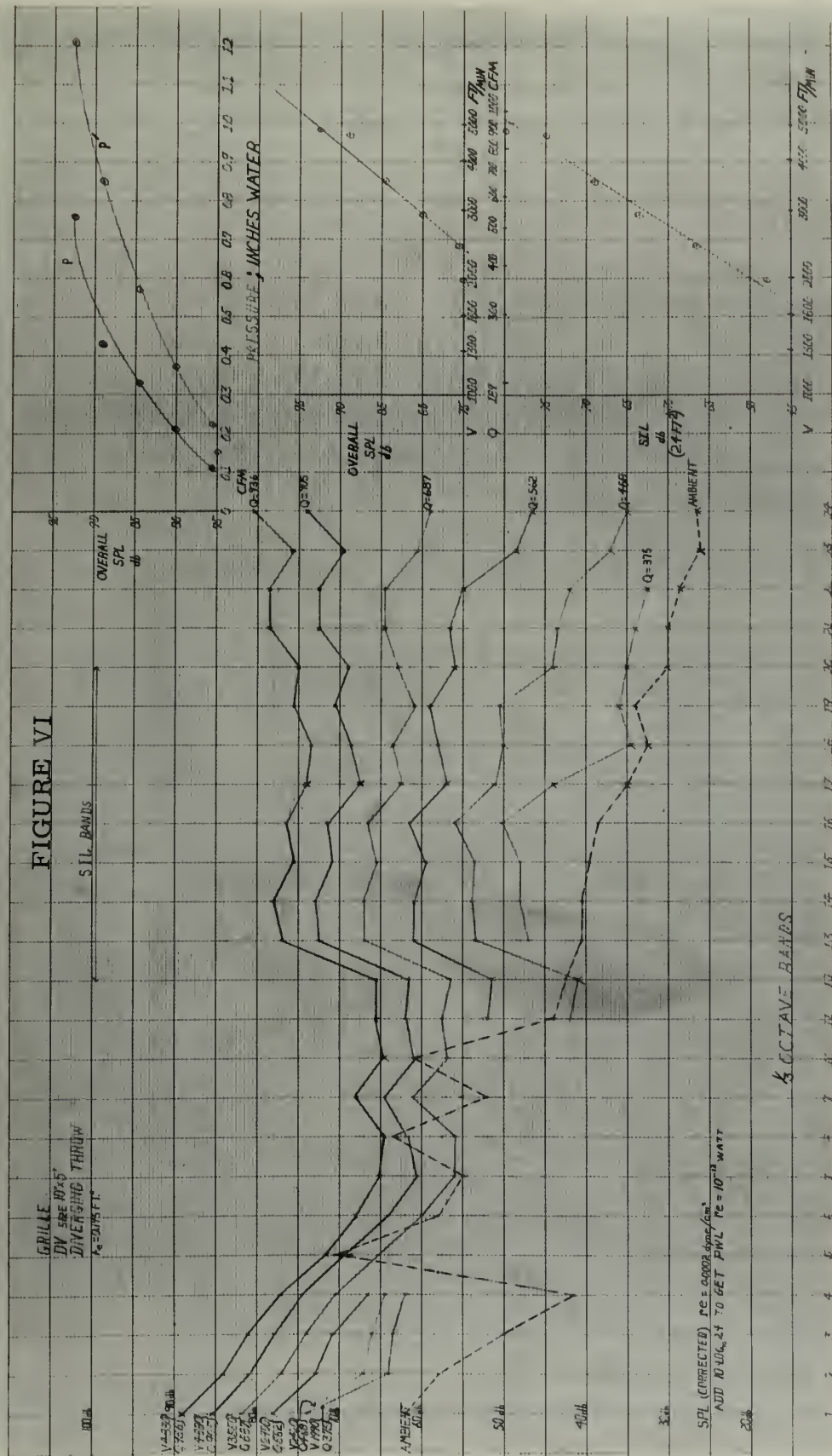


FIGURE VII

REGISTER
 10V 10V 5"
 DAMPER & OPEN
 DIVERGING THROW
 $A = 300 \text{ FT}^2$

SIL BANDS

OVERALL
 SPL
 dB

PRESSURE, INCHES WATER

V-530
 Q-572

V-460
 Q-440

V-320
 Q-320

V-280
 Q-280

V-240
 Q-240

V-200
 Q-200

V-160
 Q-160

V-120
 Q-120

V-80
 Q-80

V-40
 Q-40

V-20
 Q-20

V-10
 Q-10

V-5
 Q-5

V-2.5
 Q-2.5

V-1.25
 Q-1.25

V-0.625
 Q-0.625

V-0.3125
 Q-0.3125

V-0.15625
 Q-0.15625

V-0.078125
 Q-0.078125

V-0.0390625
 Q-0.0390625

V-0.01953125
 Q-0.01953125

V-0.009765625
 Q-0.009765625

V-0.0048828125
 Q-0.0048828125

V-0.00244140625
 Q-0.00244140625

V-0.001220703125
 Q-0.001220703125

V-0.0006103515625
 Q-0.0006103515625

V-0.00030517578125
 Q-0.00030517578125

V-0.000152587890625
 Q-0.000152587890625

V-7.629E-05
 Q-7.629E-05

V-3.814E-05
 Q-3.814E-05

V-1.907E-05
 Q-1.907E-05

V-9.535E-06
 Q-9.535E-06

V-4.767E-06
 Q-4.767E-06

V-2.384E-06
 Q-2.384E-06

V-1.192E-06
 Q-1.192E-06

V-5.96E-07
 Q-5.96E-07

SPL
 dB

$\rho = 0.0002 \text{ dyne/cm}^2$

$\rho = 0.0002 \text{ dyne/cm}^2$

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$\rho = 0.0002 \text{ dyne/cm}^2$

OCTAVE BANDS

SPL
 dB

Q CFM

Q CFM

Q CFM

Q CFM

Q CFM

Q CFM

Q CFM

Q CFM

FIGURE VIII

REGISTER
TYPE DOV SIZE 10x5"
DAMPER FULL OPEN
DIVERGING THROW
 $A = 0.95 \text{ FT}^2$

20

SILENCERS

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OVERALL
SPL
dB

70

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70

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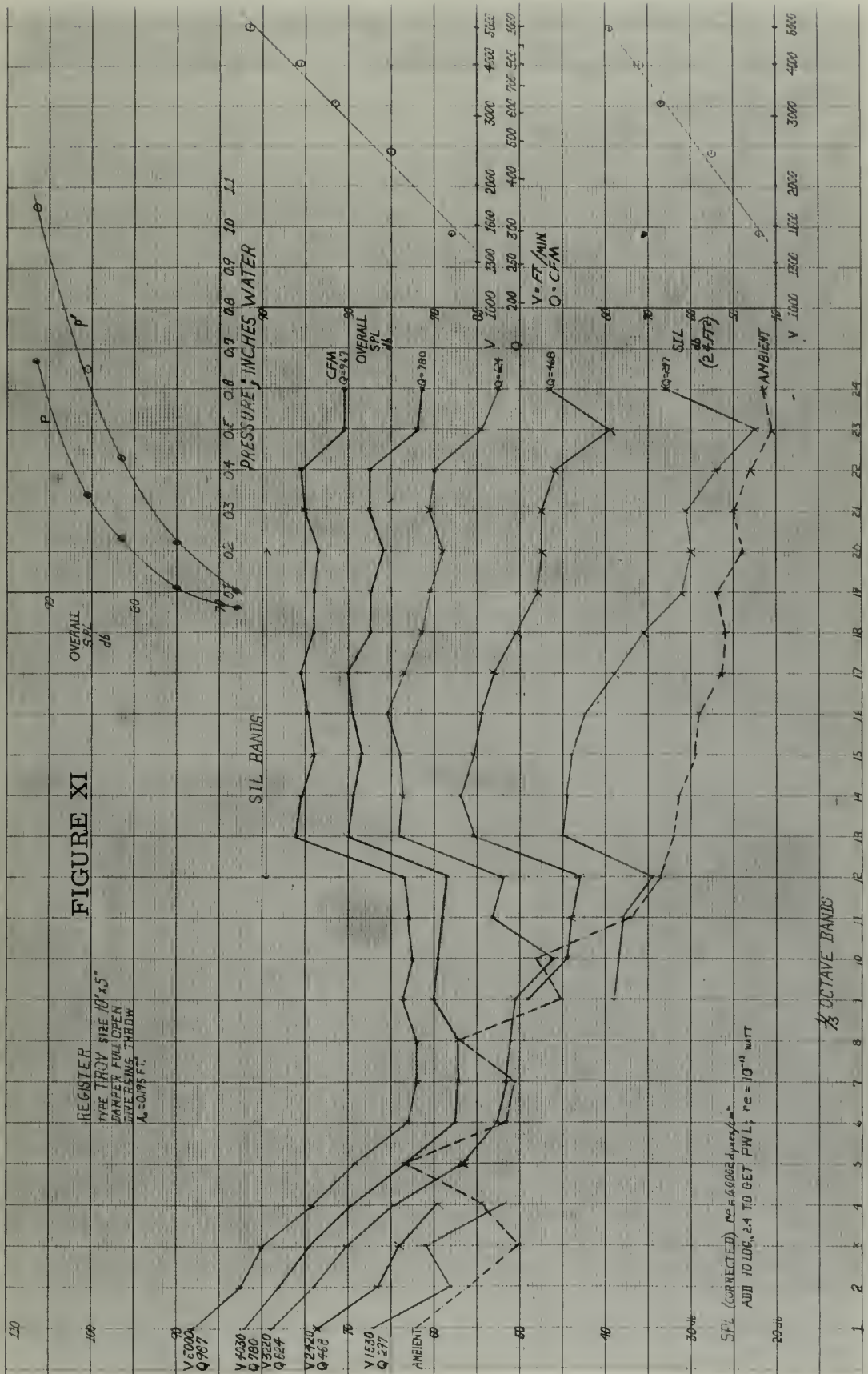
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[illegible]

SFL (CORRECTED) $P_e = 6.66 \text{ mW}$
ADD 10 LOG P_e TO GET PWT, $P_e = 10^{-13} \text{ WATT}$

9P02





FIGURE XV

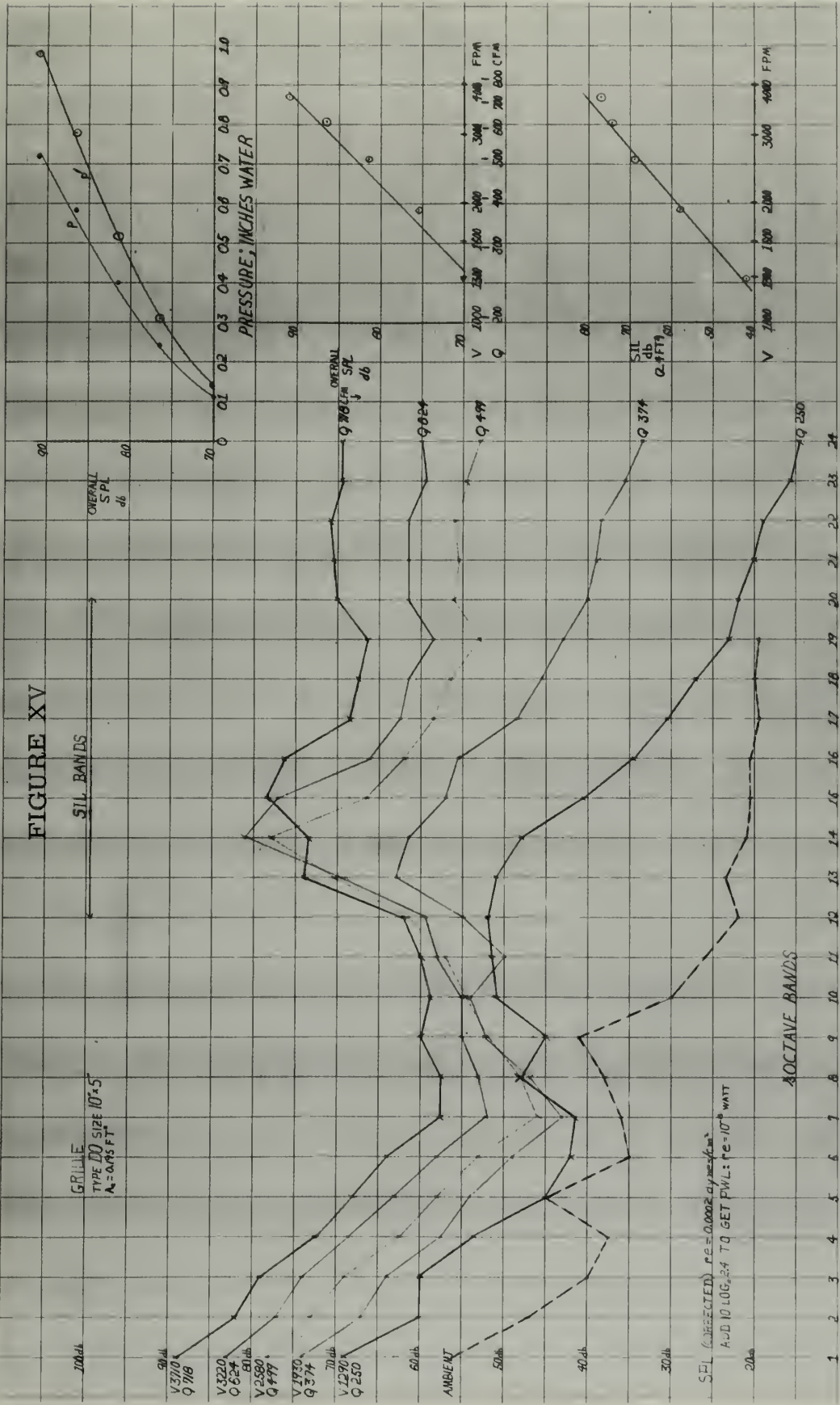


FIGURE XVI

GRILLE
TYPE 138 (STAMPED 3/8" MESH)
SIZE 10 x 5"
 $A_c = 0.285 \text{ ft}^2$

SIL HANDS

V 4800
Q 1090

V 4200
Q 936

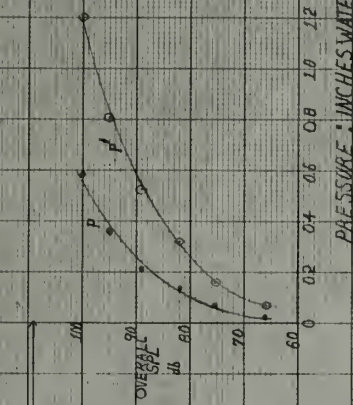
V 3600
Q 780

V 3000
Q 624

V 2400
Q 468

V 1800
Q 312

AMBIENT



PRESSURE, INCHES WATER

Q = 1090 CFM

Q = 936 CFM

Q = 780 CFM

Q = 624 CFM

Q = 468 CFM

Q = 312 CFM

Q = 1090 CFM

Q = 936 CFM

Q = 780 CFM

Q = 624 CFM

Q = 468 CFM

Q = 312 CFM

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Q = 312 CFM

Q = 1090 CFM

Q = 936 CFM

Q = 780 CFM

Q = 624 CFM

Q = 468 CFM

Q = 312 CFM

SPL (CORRECTED) TO 0.0002 dynes/cm²
ADD 10 LOG 24 TO GET P.W.L. : $T_c = 10^{-4}$ WATT

4 OCTAVE BANDS

V 1000
Q 1000

V 1000
Q 1000

V 1000
Q 1000

V 1000
Q 1000

V 1000
Q 1000

V 1000
Q 1000

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Q 1000

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Q 1000

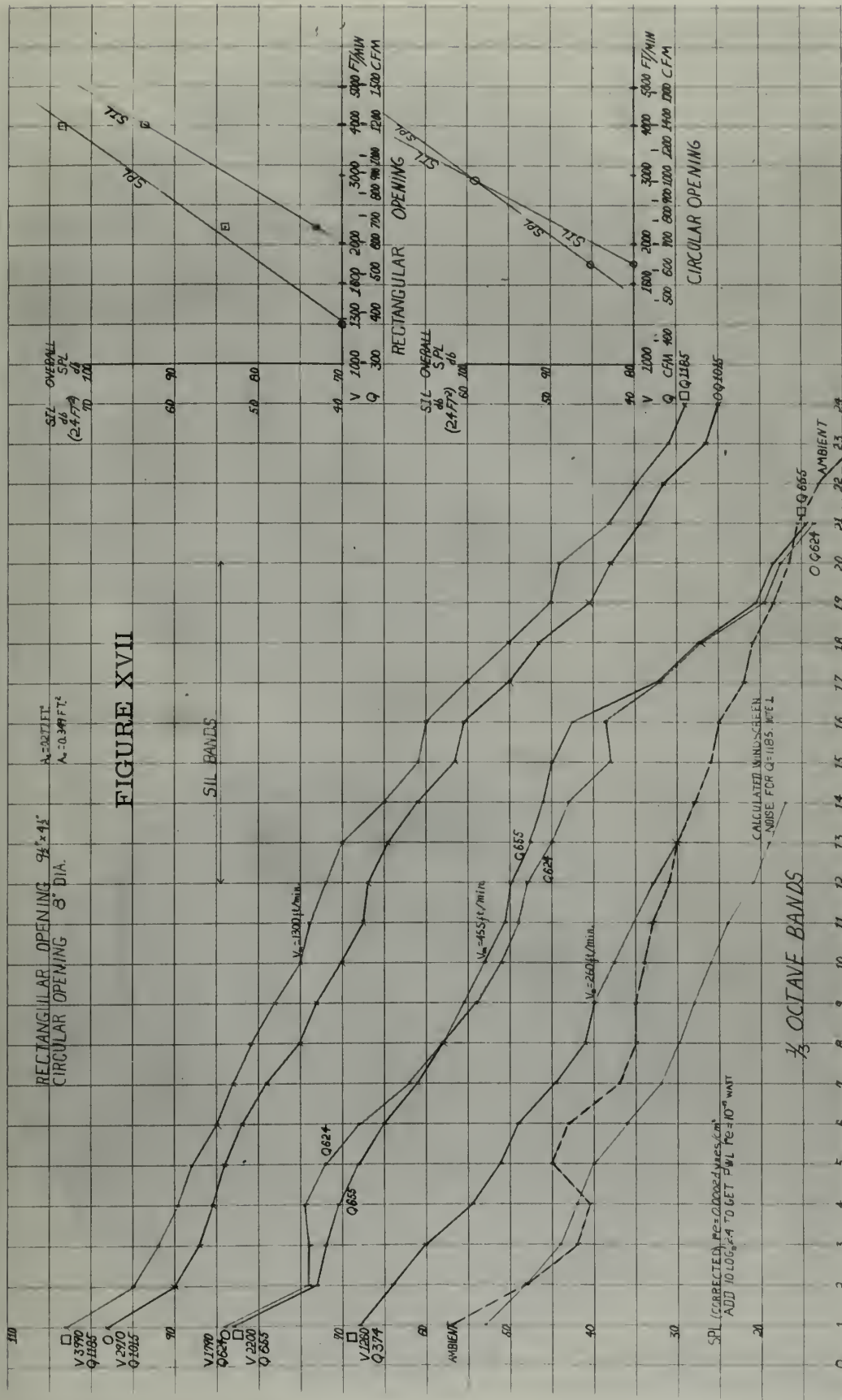
V 1000
Q 1000

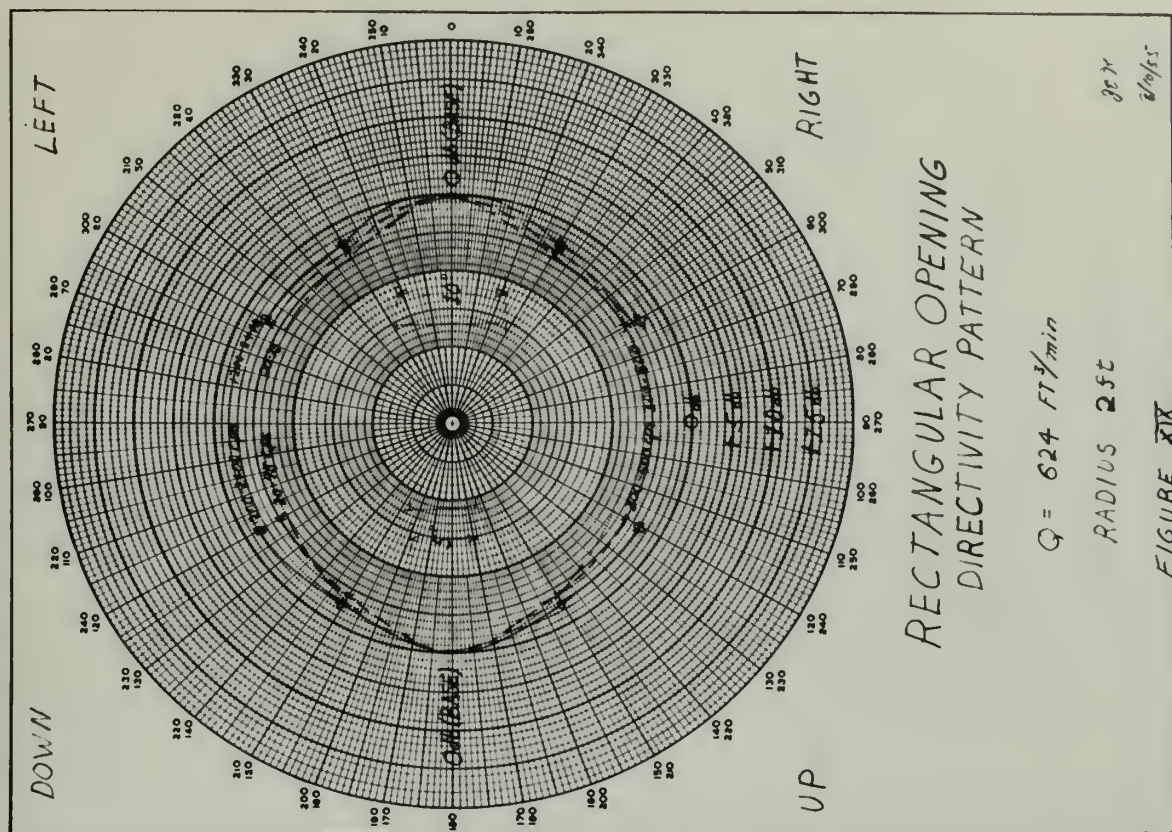
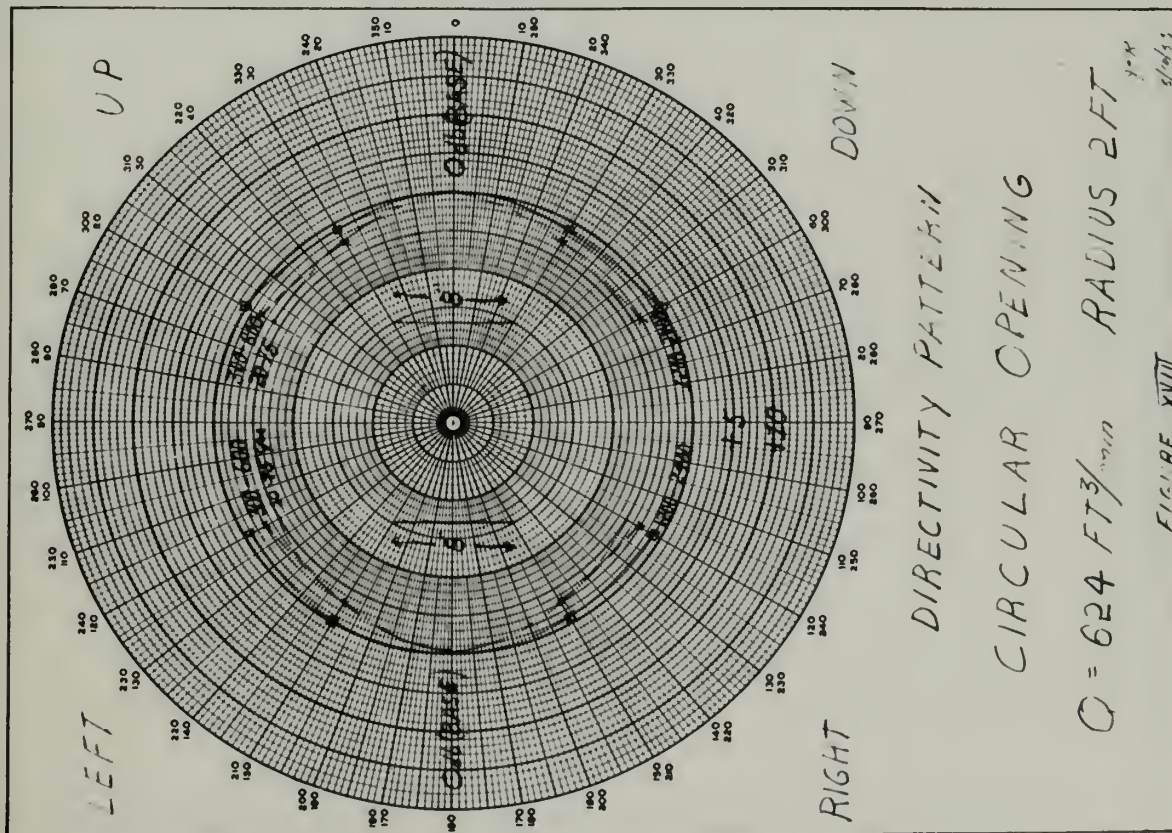
V 1000
Q 1000

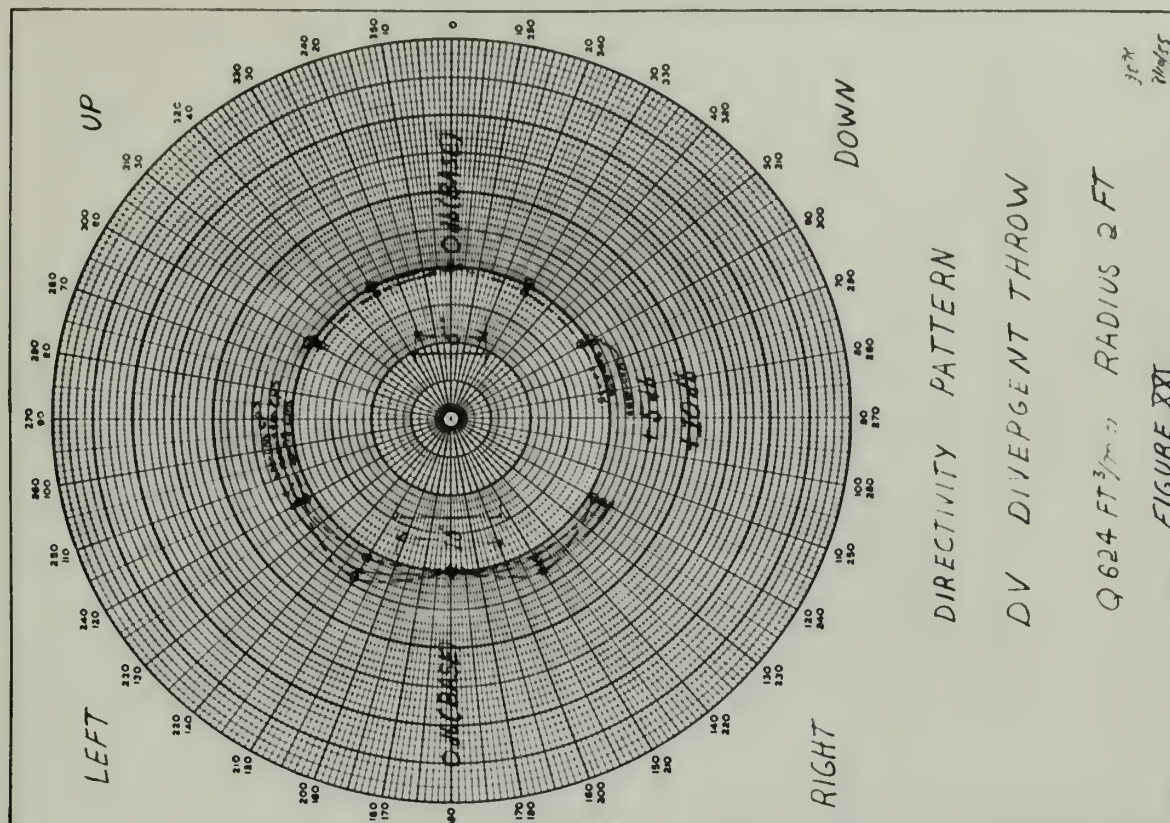
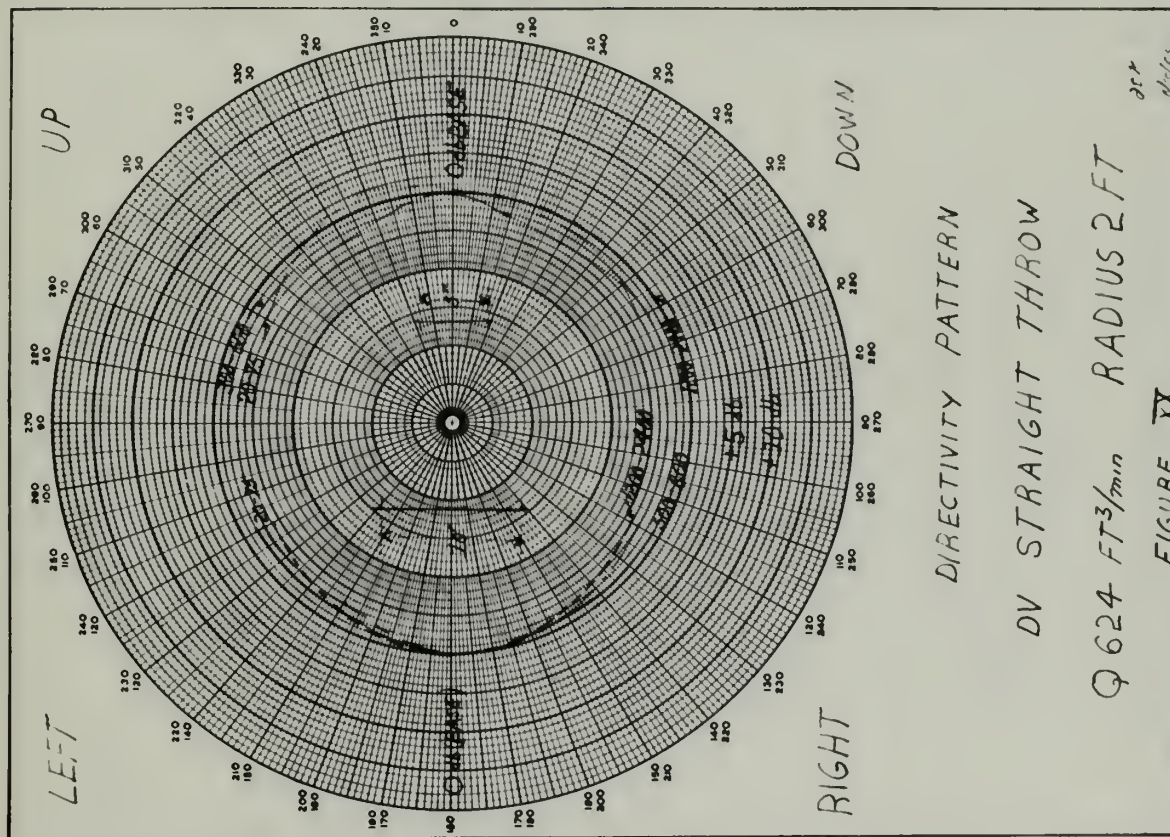
V 1000
Q 1000

V 1000
Q 1000

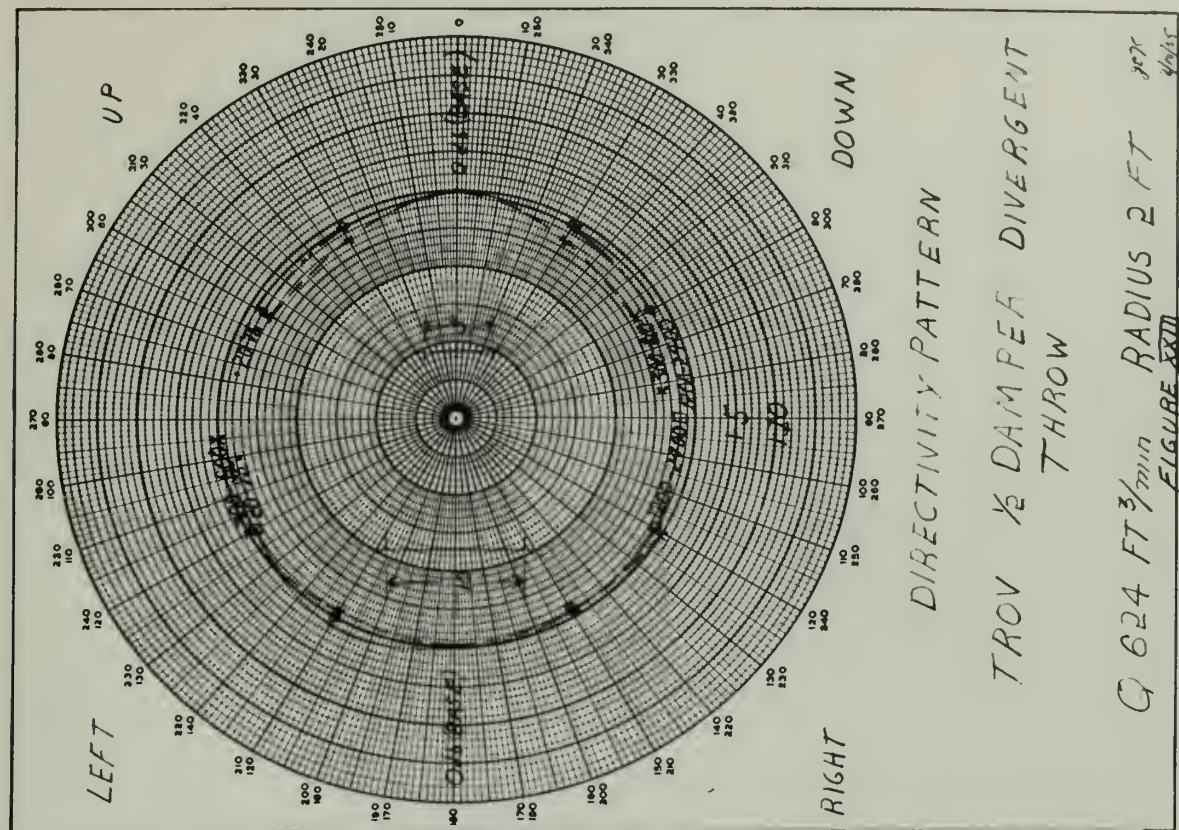
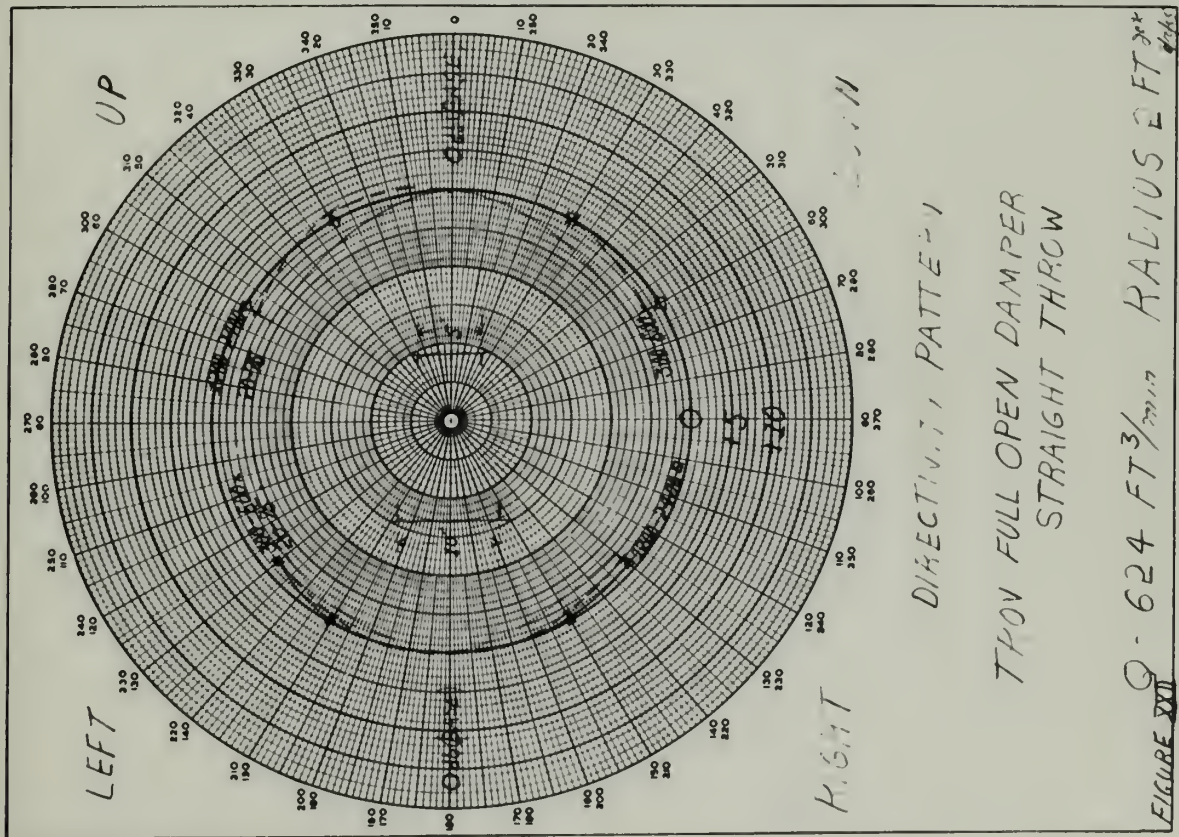
V 1000
Q 1000

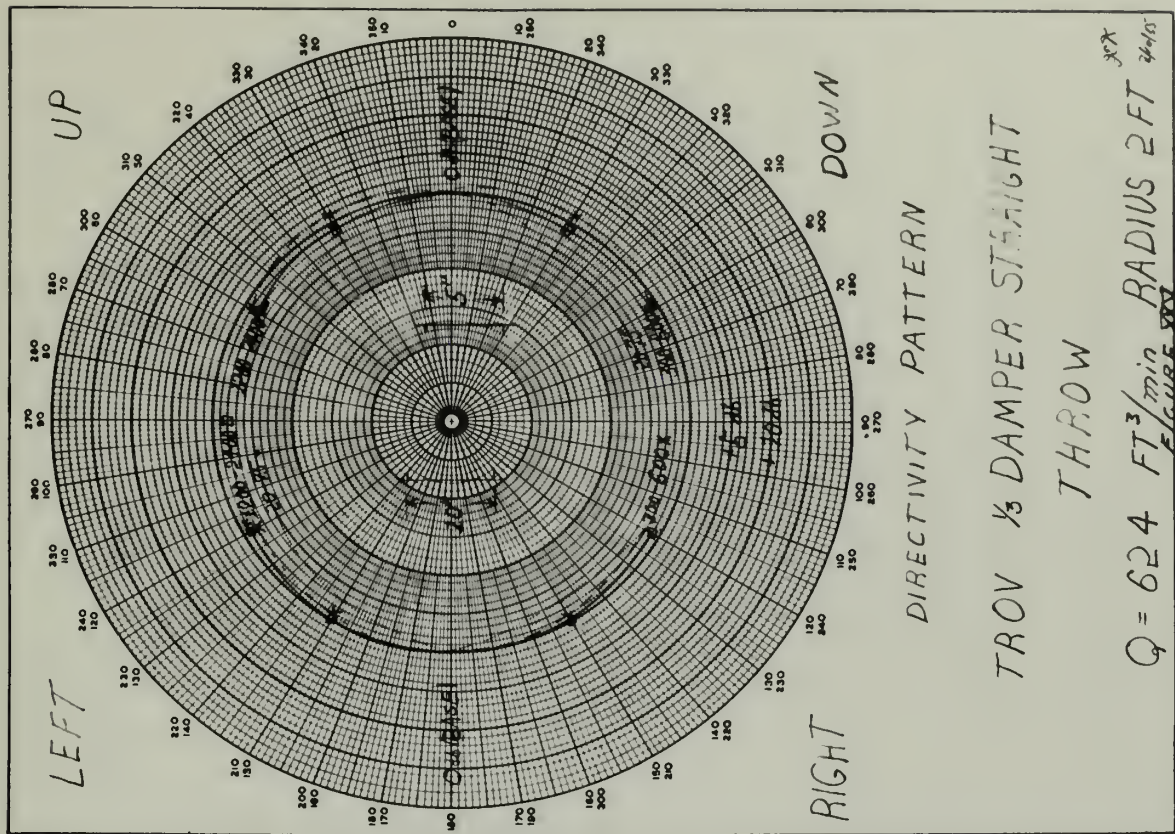
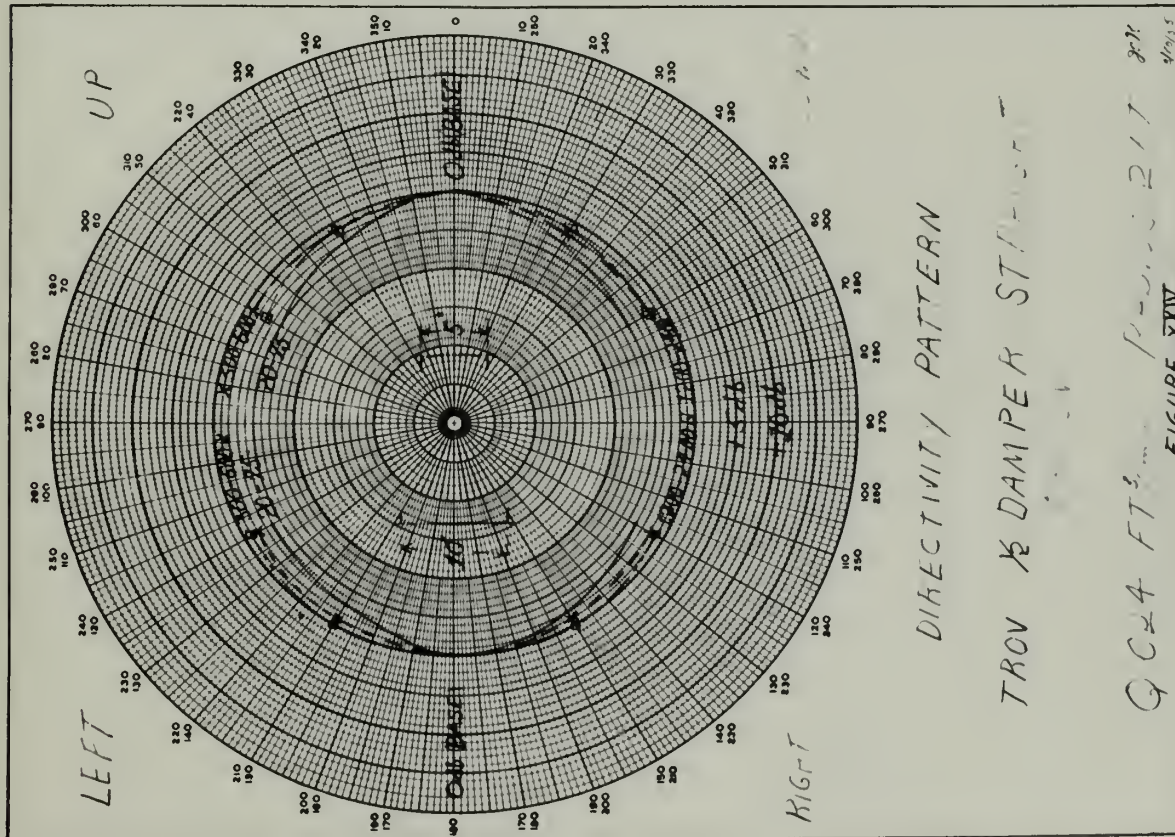


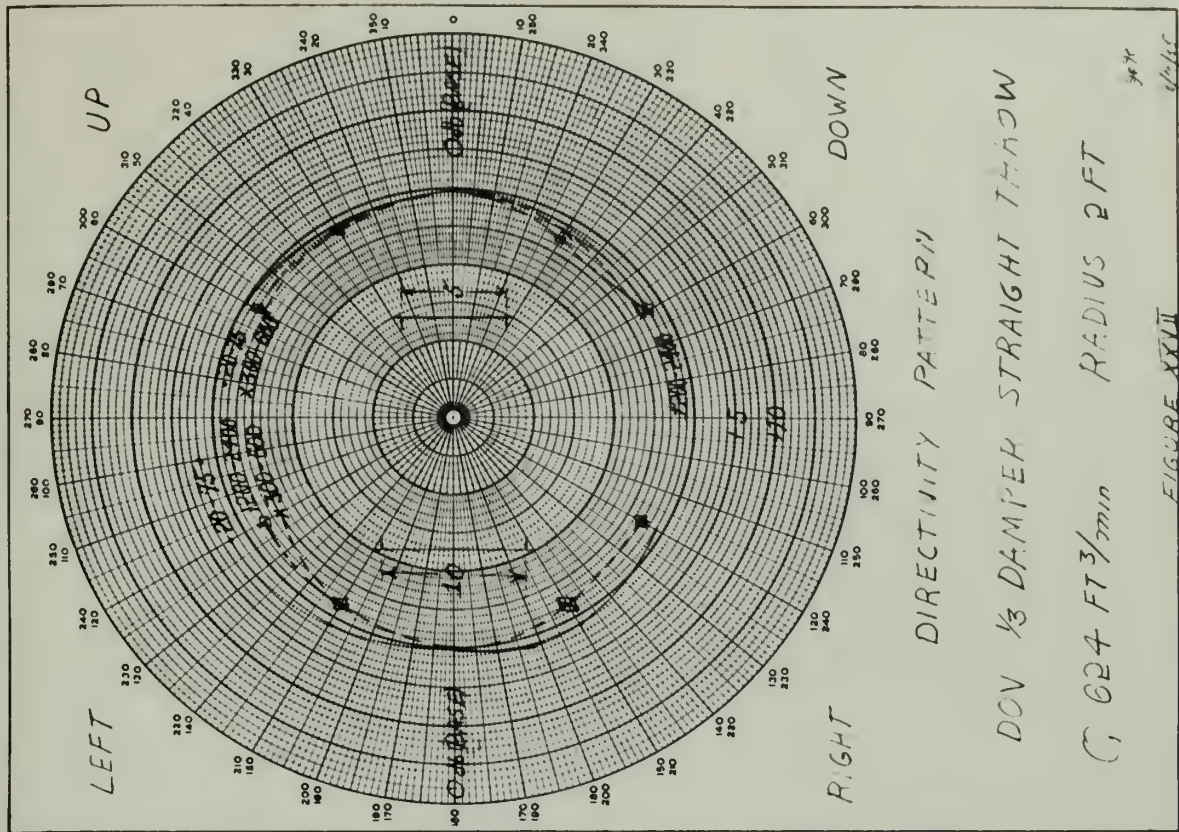
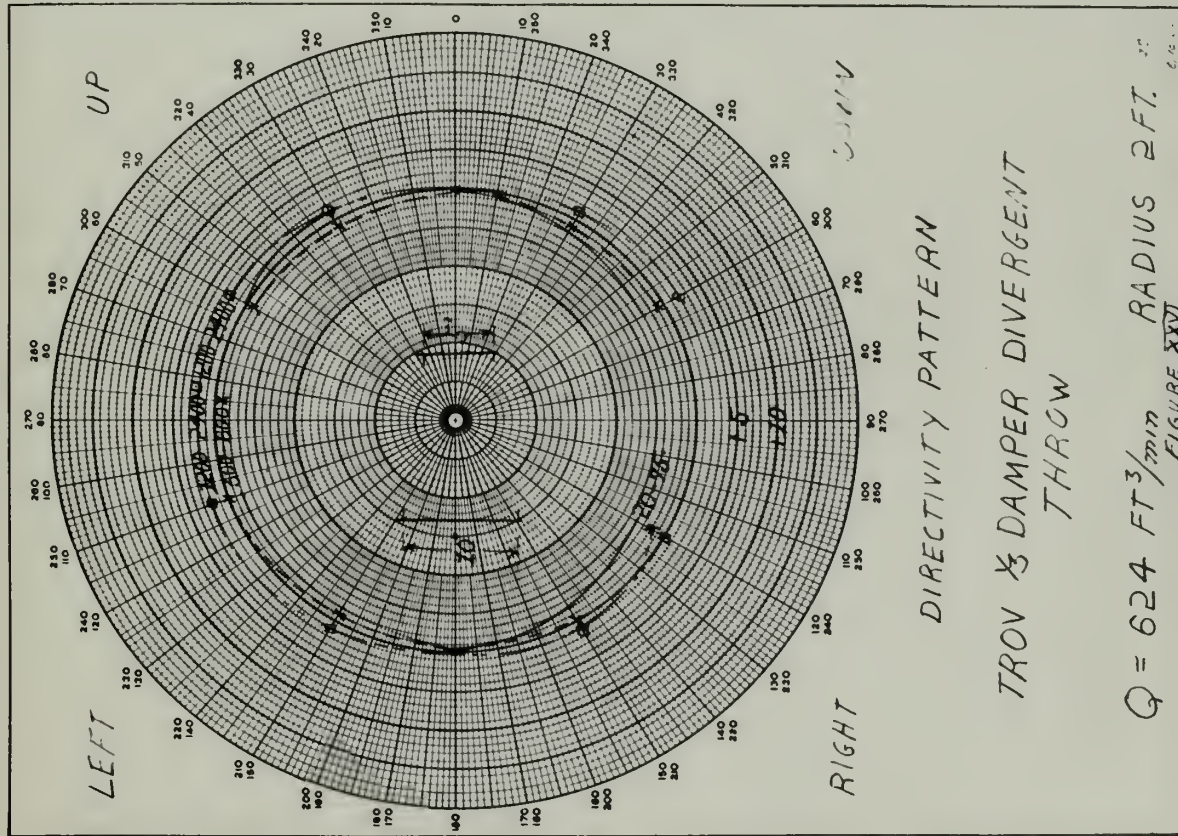


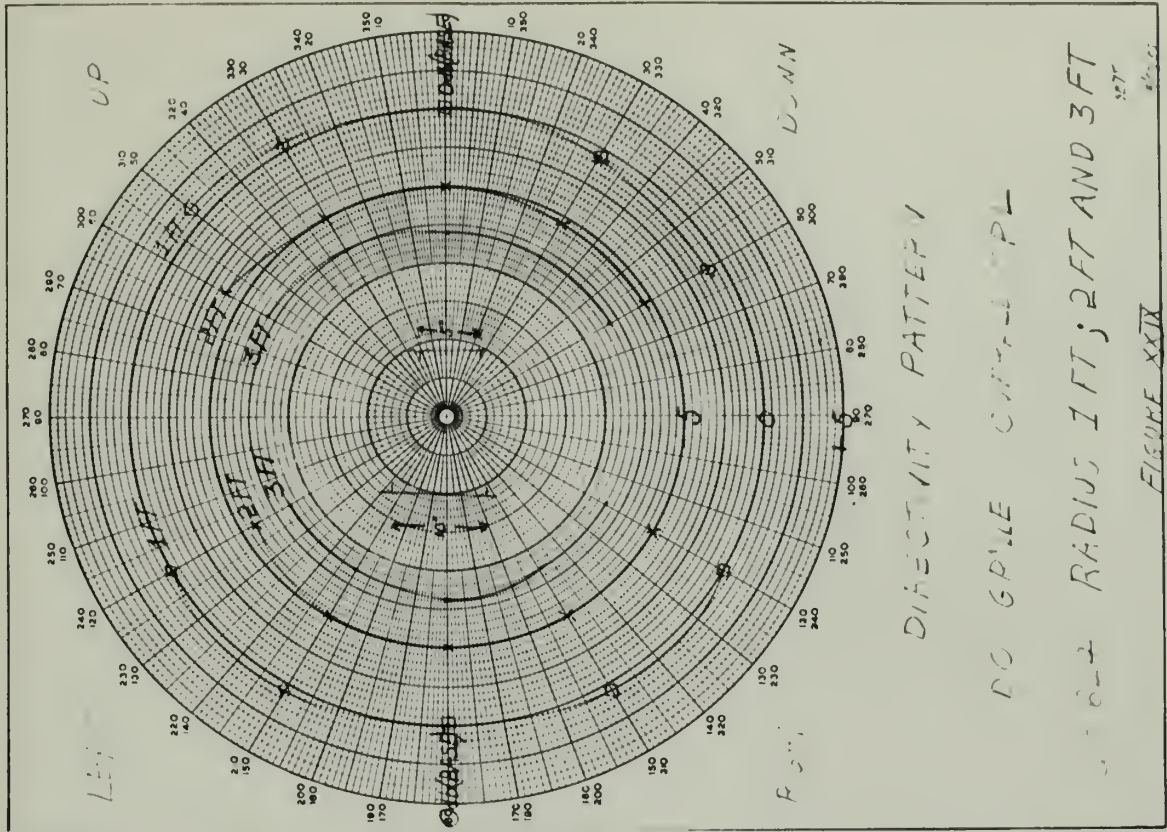
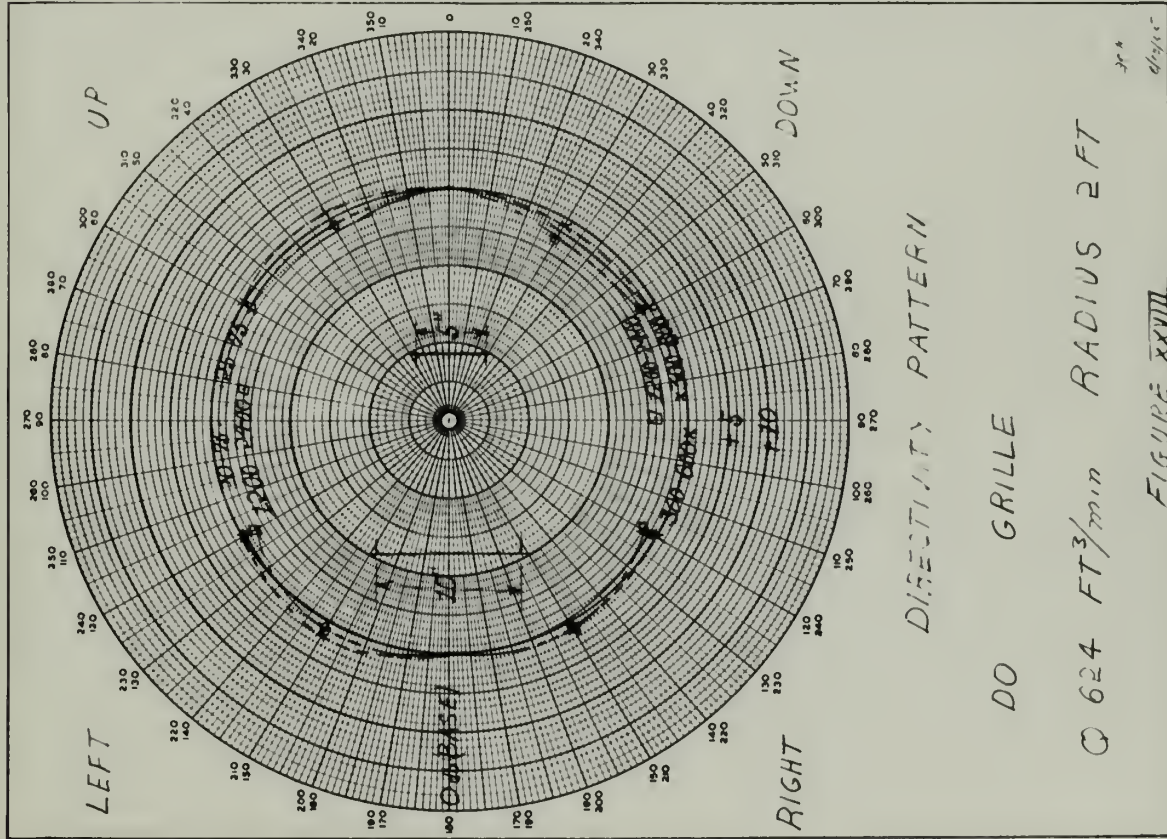


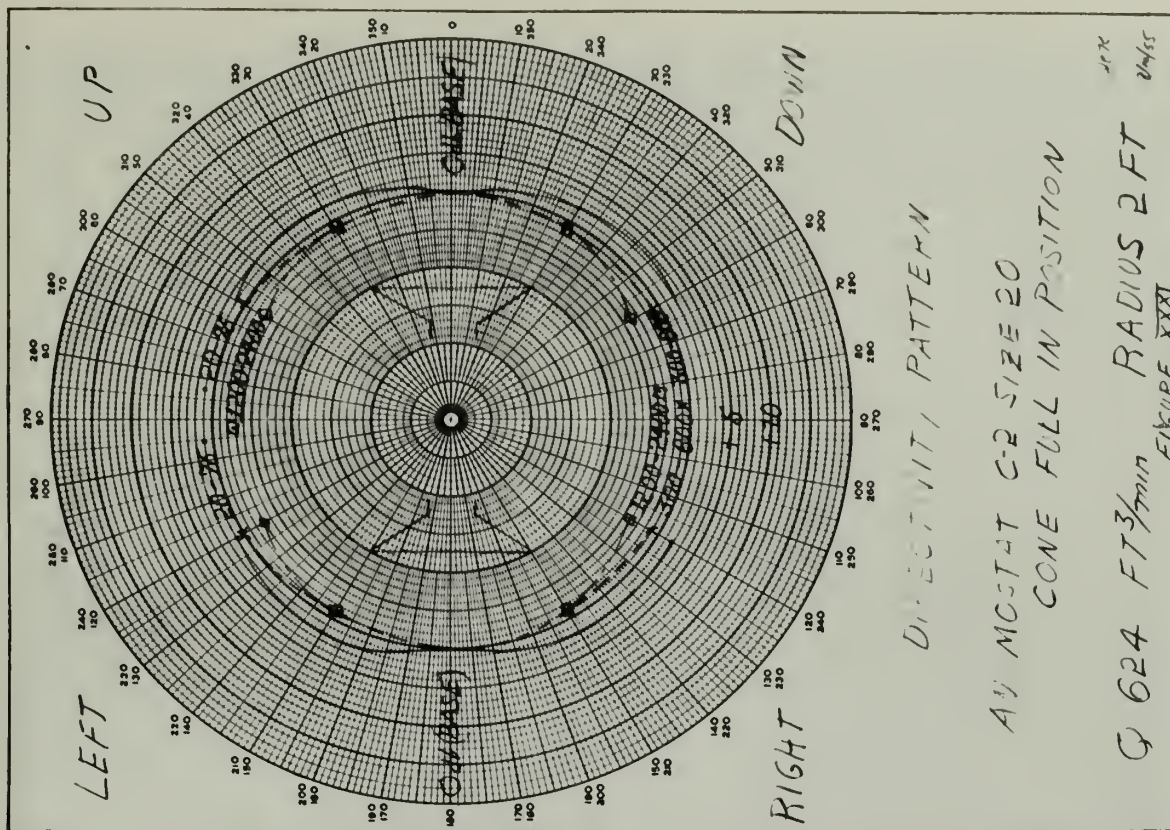
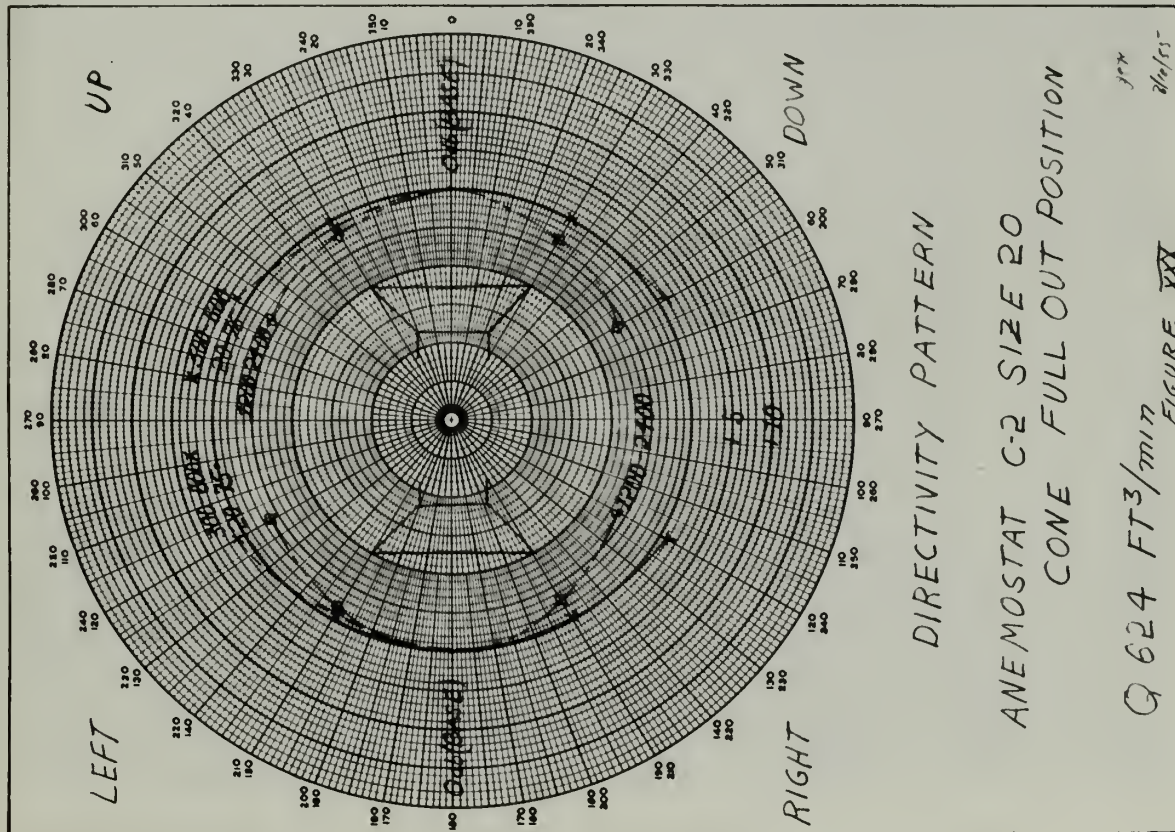


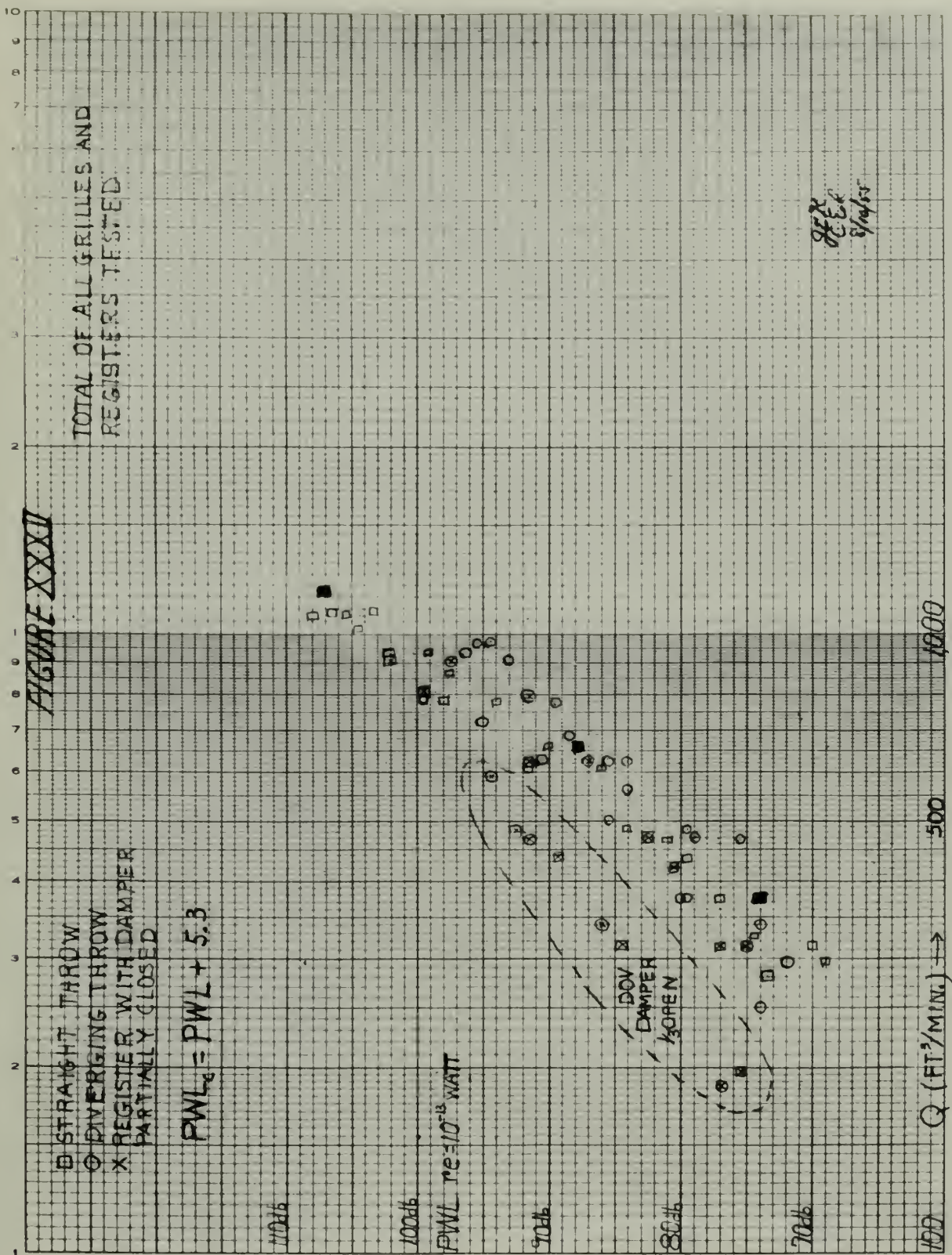












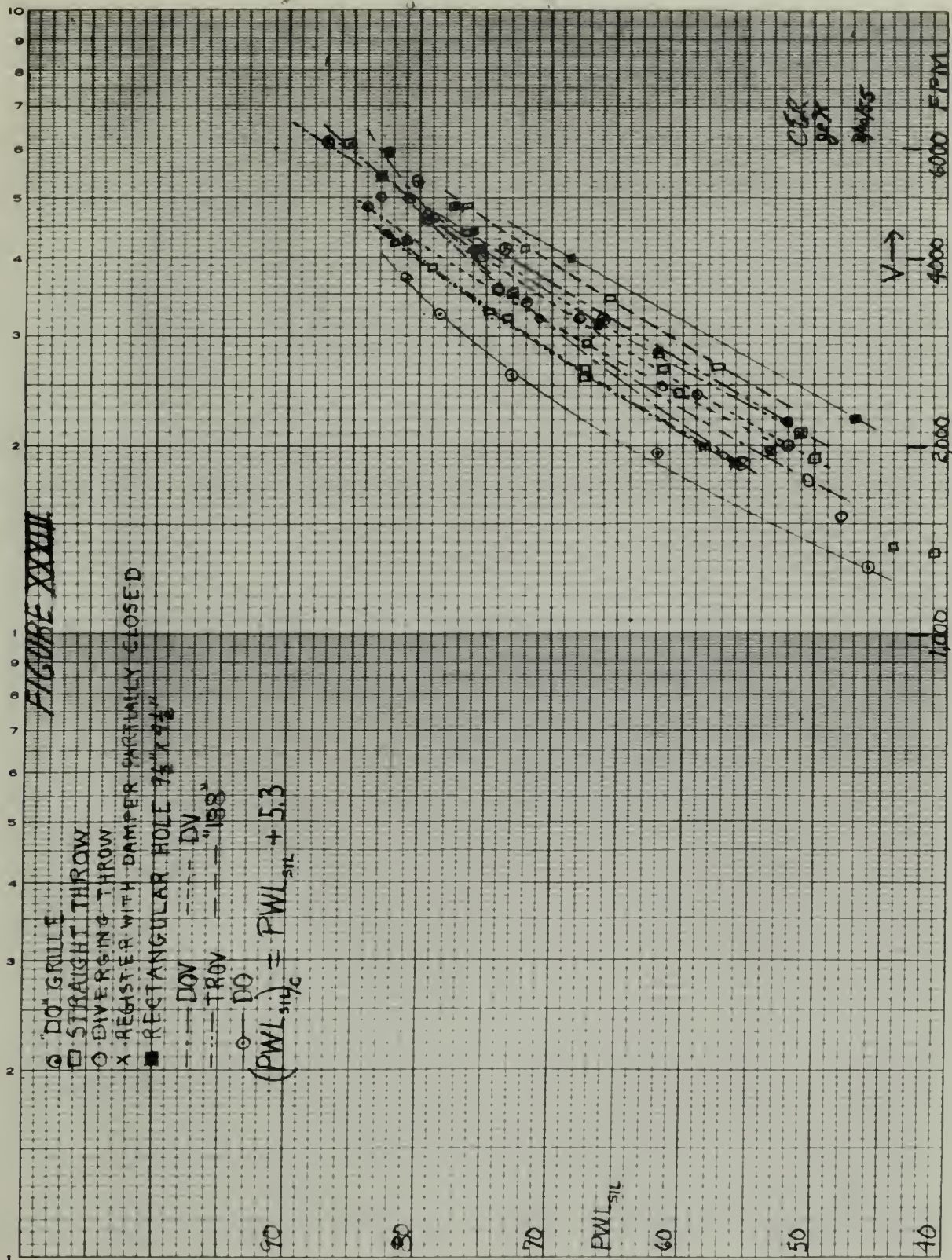
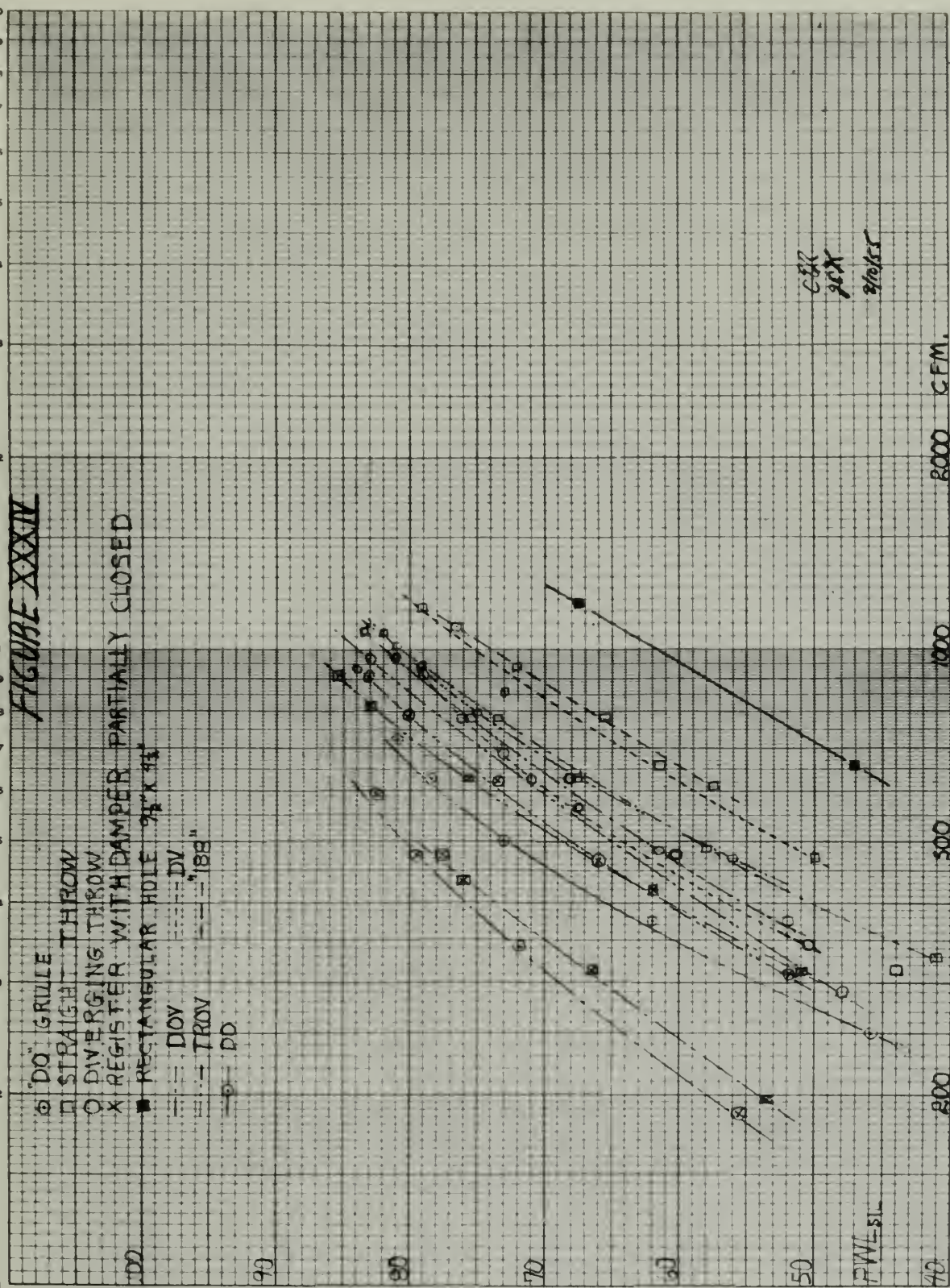
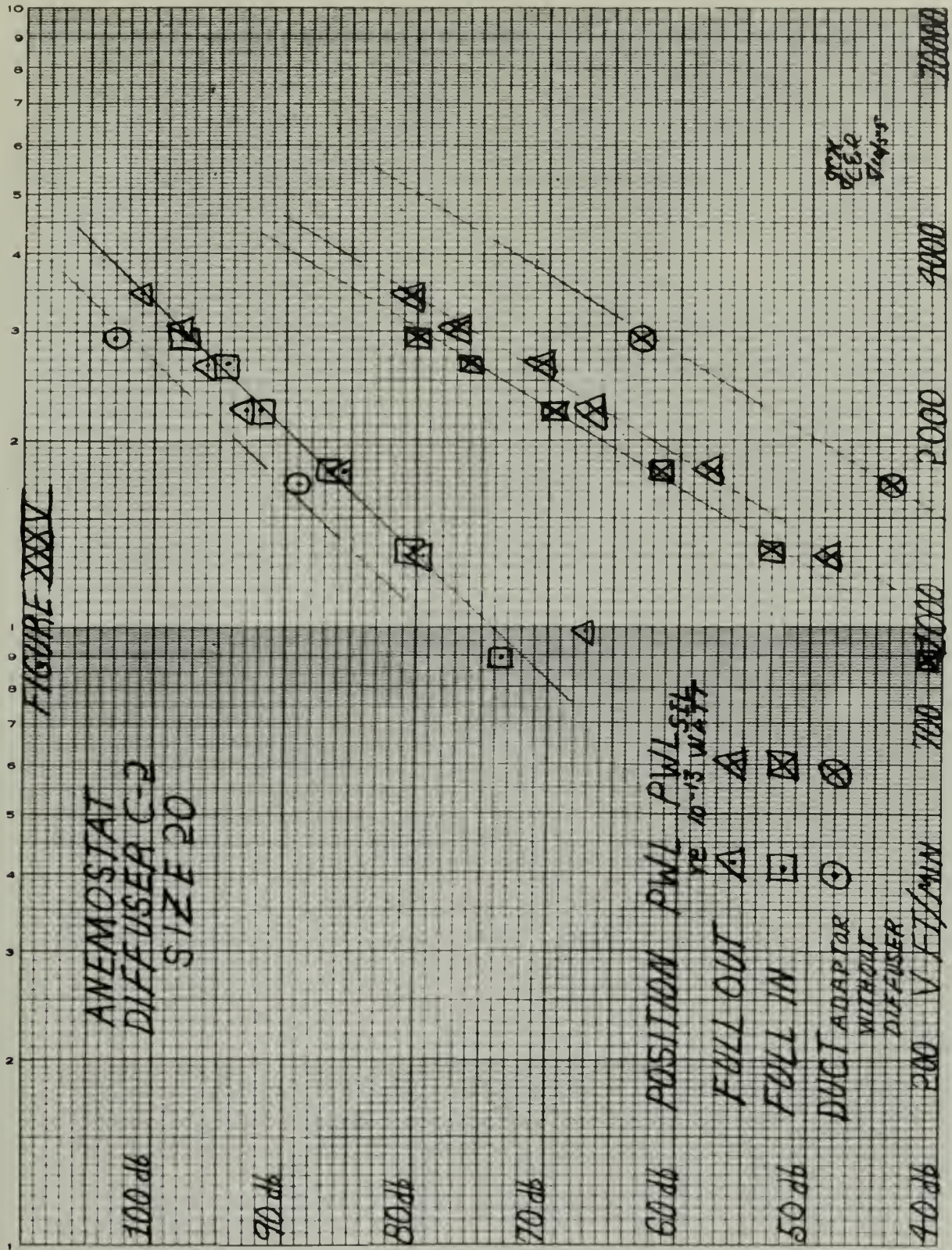
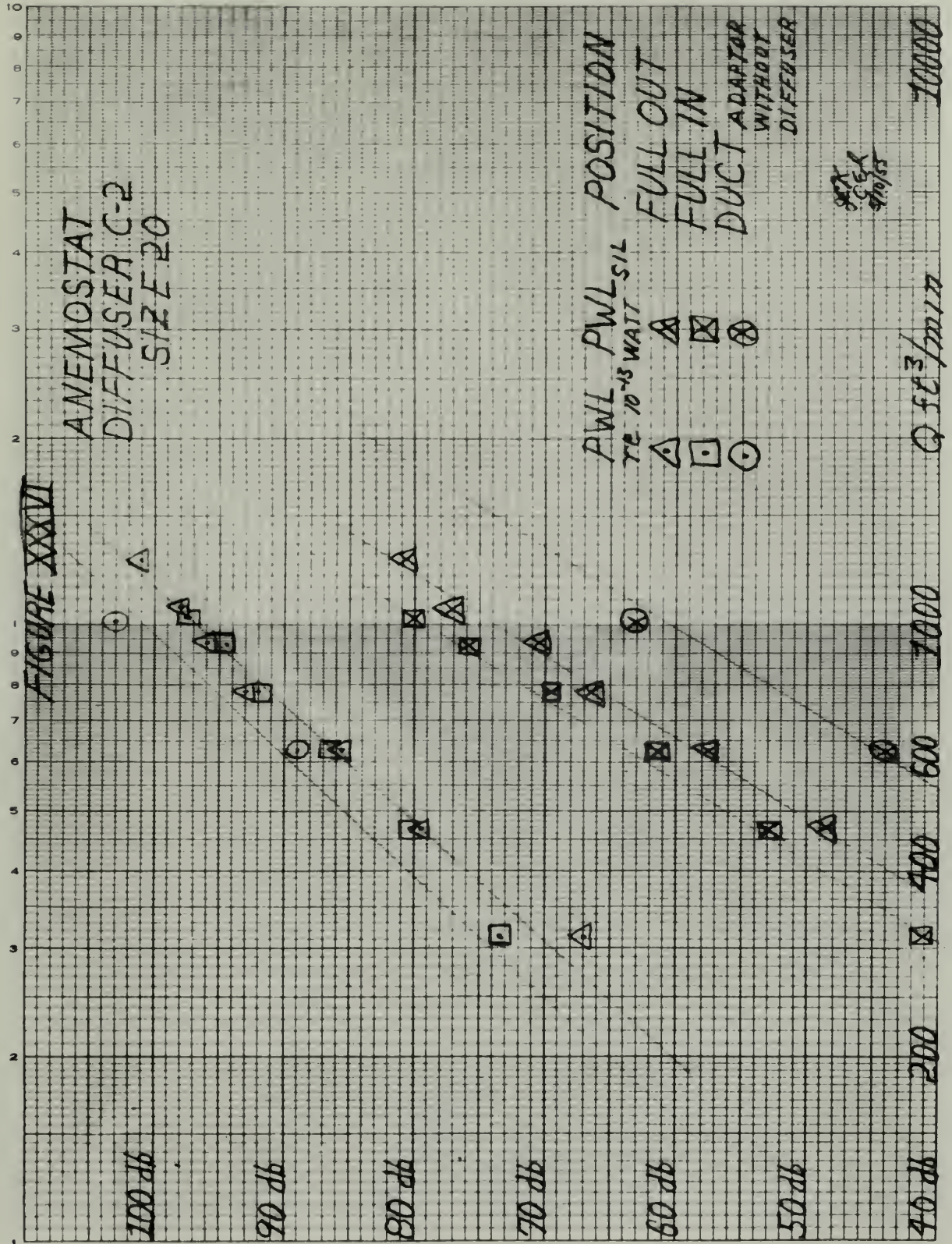


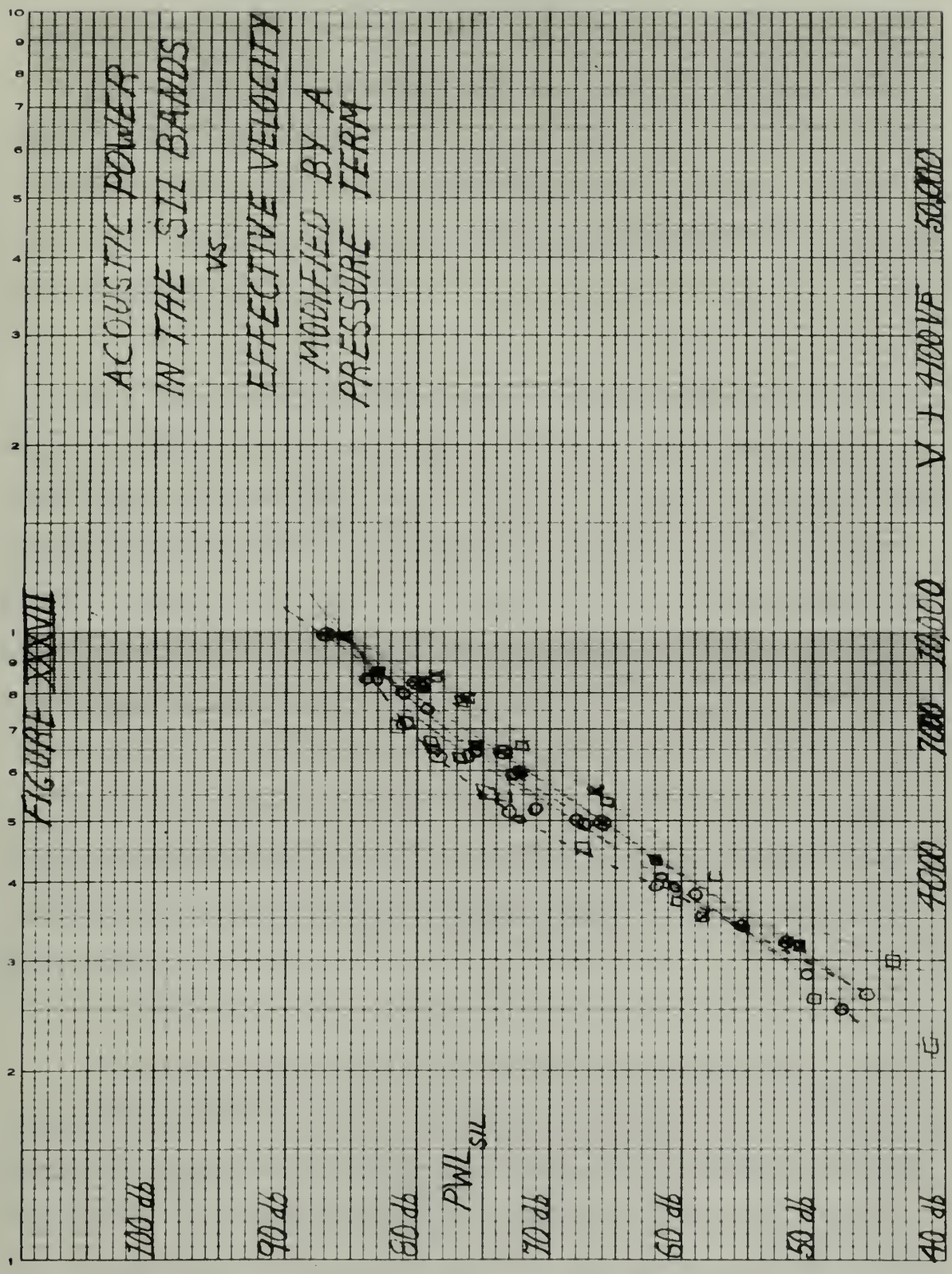
FIGURE XXXIV

- 10" GRILLE
- STRAIGHT THROW
- DIVERGING THROW
- X REGISTER WITH DAMPER PARTIALLY CLOSED
- RECTANGULAR HOLE 24" X 48"
- DOV
- TROV
- DO









VI DISCUSSION OF RESULTS

The various spectra curves show that the major portion of the acoustic power was contained in the lower bands of the frequency range investigated. (See Figs. III through XVIII.) The total acoustic power measured in the bands investigated varied approximately as the velocity to the sixth power.

As a function of volumetric rate of flow, the type of air throw had little effect upon the overall power level as long as the damper was not more than one-half closed. (See Fig. XXXII.) On the other hand, the shape of the spectrum was affected to a significant degree by the position of the dampers and the setting of the fins. The diverging throw and closing off of the dampers tended to accentuate the noise generated in the higher bands.

It is these higher bands that interest the designer most. In particular he is interested in the speech interference level bands. These are bands 12 through 20 for the particular one-third octave band filter being used.

To meet the needs of the designer the new quantity PWL_{SIL} was formulated. Its definition has previously been given in Chapter III. This quantity was found to vary widely with damper position and throw. (See Fig. XXXIV.) In this case the PWL_{SIL} for the open hole was less than the straight throw, which in turn was less than the diverging throw and so on to the register with damper in the one-third open position which

VI. DISCUSSION OF RESULTS

The various spectra curves show that the major portion of the acoustic power was confined in the lower bands of the frequency range investigated. (See Fig. IX through XVII.) The total acoustic power measured in the bands investigated varied approximately as the velocity in the sixth power.

As a function of volumetric rate of flow, the type of air flow had little effect upon the overall power level as long as the damper was not more than one-half closed. (See Fig. XXIII.) On the other hand, the shape of the spectrum was affected to a significant degree by the position of the damper and the setting of the flow. The diverging throw and closing off of the damper tended to accentuate the noise generated in the higher bands.

It is these higher bands that interest the designer most. In particular, he is interested in the speech interference level bands. These are bands 12 through 20 for the particular one-third octave band filter being used.

To meet the needs of the designer the new quantity PWL_{III} was formulated. Its definition has previously been given in Chapter II. This quantity was found to vary directly with damper position and throw. (See Fig. XXIV.) In this case the PWL_{III} for the open hole was less than the straight throw, which in turn was less than the diverging throw and so on to the register with damper in the one-third open position which

had the highest value. This was to be expected; reduction of the effective area causes an increase in local velocities around the frets, fins or dampers. Theory (6) shows that the total power radiated is proportional to velocity to some power greater than one and is six in the particular case of the noise radiated by air flow past a cylindrical rod.

It would be desirable from the viewpoint of the designer to reduce all curves of PWL_{SIL} to a single curve or narrow band which could readily be expressed as some function of velocity, area, power loss in the wake, or pressure drop across the device. Thus if some common parameter for all the grilles and registers tested could be found, then the designer would have to look at a single chart or equation rather than have a chart of curves for each grille and register in the catalog.

The first trial along these lines was to plot PWL_{SIL} versus effective velocity. This brought all but two curves within a range of 11 db.

In an effort to find a common parameter, various schemes were tried. The ratio of the acoustic power of the SIL bands to the product $Q \times p$ versus Q and versus V was plotted; the PWL_{SIL} versus $Q \times p$ was plotted but none of the above were as good as the PWL_{SIL} versus V .

One other scheme was tried and with some success. This was a plot of PWL_{SIL} versus $(V + a\sqrt{p})$, where "a" is a constant to be determined. (See Fig. XXXVII.) It was believed that the acoustic power in the speech interference ranges might be a function of both the effective velocity and the pressure drop across the device. The square root of

had the highest value. This was to be expected, reduction of the efflu-
 live area caused an increase in local velocities around the tube. The
 no change. Theory (4) shows that the total power required is propor-
 tioned to velocity in some power greater than one and is six in the per-
 fect case of the holes radiated by the flow past a cylindrical rod.

It would be desirable from the viewpoint of the designer to reduce
 all curves of $P_{WT_{III}}$ to a single curve or curves and which would
 readily be expressed as some function of velocity, even, power loss in
 the water, or pressure drop across the device. Then if some common
 parameter for all the profiles and segments tested could be found, then
 the designer would have to find at a single chart or equation rather
 than have a chart or curve for each profile and segment in the series.
 The first trial along these lines was to plot $P_{WT_{III}}$ versus $Q \times p$.
 This brought all but two curves within a range of 11 to

12. The two curves which were beyond the range were
 in an effort to find a common parameter, various relations were
 tried. The value of the specific power of the III, heads in the present
 $Q \times p$ versus Q and versus V was plotted. The $P_{WT_{III}}$ versus $Q \times p$ was
 plotted but none of the above were as good as the $P_{WT_{III}}$ versus V .

One other relation was tried and with some success. This was a
 plot of $P_{WT_{III}}$ versus $(V + K \times p)$, where K is a constant to be deter-
 mined. (See Fig. 10-10.) It was believed that the acoustic power in
 the space between tubes might be a function of both the effective
 velocity and the pressure drop across the device. The square root of

pressure was used since dynamic pressure is related to the square of velocity. There are two methods of selecting a value of "a": the first is to examine the curves and make an estimate of the value needed to obtain bunching of the curves, and the second, a more scientific method of determining "a", is to let "p" represent the dynamic pressure of a velocity " V_d ".

$$p = \frac{1}{2} \frac{V_d^2}{a^2}$$

where $1/a^2 = 1/2\rho$ if ρ = the density of the air.

In this investigation pressure was measured in inches of water and velocity in feet per minute; therefore, the value of "a" must also absorb the constants of conversion. This gave a value for "a" of 4100.

A plot was made of PWL_{SIL} versus $(V + a\sqrt{p})$ letting $a = 4100$ and it was found that the spread of the curves was considerably reduced, the spread being only about 2 db in the lower and upper region with about a 9 db spread in the center region. The upper and lower region are thus comparable to the error in the reading of the instruments on which the data were taken.

It must be emphasized that these curves are based on a single size of grille. Some other parameter must be used in order to extrapolate these results to different sizes.

pressure was used which depends primarily is related to the speed of velocity. There are two methods of determining a value of α : the first is to assume that the rate of change of pressure at the value needed to obtain pressure in the water, and the second, a more accurate method of determining α , is to let α represent the dynamic pressure of a velocity $\frac{1}{2} V^2$.

$$\frac{1}{2} V^2 = \frac{p}{\rho}$$

where $\frac{1}{2} V^2 = 1/2 \times 11^2 = 60.5$ is the density of the air.

In this investigation pressure was measured in inches of water and velocity in feet per minute; therefore, the value of α must also always be converted to inches of water. This gives a value for α of 4100.

A plot was made of $\frac{p}{\rho V^2}$ versus $(V + \alpha \sqrt{p})$ in inches of water and it was found that the trend of the curves was considerably reduced. The trend being only about 5 in the lower and upper region with about a 9 in trend in the water region. The upper and lower region are thus comparable to the river in the middle of the instrument on which the data were taken.

It must be emphasized that these curves are based on a single set of data. Some other reference must be made in order to extend points these points at different areas.

Directivity data for all the various devices showed them to be substantially non-directive under the conditions tested. This was to be expected in the lower bands because of the small dimensions of the grilles tested with respect to a wave length.

Theory data for all the various devices shown here to be
 substantially consistent with the theoretical model. This was in
 the region of the first sharp peak of the small diameter of the
 system used with respect to a wave length.

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 substantially consistent with the theoretical model. This was in
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 system used with respect to a wave length.

The theory data for all the various devices shown here to be
 substantially consistent with the theoretical model. This was in
 the region of the first sharp peak of the small diameter of the
 system used with respect to a wave length.

VII CONCLUSIONS

1. The total acoustic power in the frequency range investigated varied as the sixth power of the air velocity.
2. The acoustic power in the speech interference level varied between the 7.5th to 8.0th power of velocity.
3. The acoustic power in the SIL frequencies generated by grilles and registers of the same size can be related by means of the parameter $(V + a\sqrt{p})$ where "V" is the effective velocity, "p" is the pressure drop across the grille, and "a" is a constant which relates dynamic pressure to velocity.

THE CHARTER

I. The total acoustic power in the frequency range investigated is the sum of the power in the two components.

II. The acoustic power in the speech interference level varies between 1.5 and 4.0 dB power of velocity.

III. The acoustic power in the 100 Hz frequency band is given by the equation $P = 10^{-10} V^2$ where V is the velocity in cm/sec. The power in the 100 Hz band is also given by the equation $P = 10^{-10} V^2$ where V is the velocity in cm/sec. The power in the 100 Hz band is also given by the equation $P = 10^{-10} V^2$ where V is the velocity in cm/sec. The power in the 100 Hz band is also given by the equation $P = 10^{-10} V^2$ where V is the velocity in cm/sec.

VIII RECOMMENDATIONS

It is recommended that grilles and registers of several different geometrical sizes and shapes be tested with the same apparatus as was used for this investigation. This should be done to determine whether the characteristic rise in noise that was found at the thirteenth octave band might be associated with the geometrical dimensions of the terminal opening rather than the characteristics of the grille itself. It is noted that the wave length of the thirteenth center band frequency is approximately equal to the long dimension of the adapter terminal opening. The fact that the rise is noted only in cases involving restricted flow would tend to substantiate this possibility.

The strong correlation that was found between the acoustic power in the speech interference bands and the effective velocity modified by $4100 \sqrt{p}$ should be checked and substantiated by further tests and data.

The frequency characteristics in most cases indicate that the low frequency acoustical power output is governed by a different parameter than is the high frequency output. A further study should be made with the objective of finding these parameters.

The results of this investigation show that the noise power in the speech interference varies approximately as the eighth power of the velocity. The fact that noise generated from turbulence alone varies as the eighth power of the velocity would indicate that the acoustic power being generated in the SIL bands is due mainly to turbulence. The lower

It is recommended that further and complete and detailed information be furnished to the Bureau and the Department of Justice as soon as possible. This should be done in order to determine whether the character of the crime is such that it should be treated as a crime against the person or as a crime against the property. It is also suggested that the Bureau be kept advised of the progress of the investigation and of the results of the same. It is further suggested that the Bureau be kept advised of the results of the investigation and of the results of the same. It is further suggested that the Bureau be kept advised of the results of the investigation and of the results of the same.

The strong correlation that was found between the acoustic power in the speech measurement bands and the objective velocity modified by 1000 Hz should be checked and substantiated by further tests and data.

The frequency characteristics in most cases indicate that the low frequency section must be removed by a different parameter than is the high frequency output. A further study should be made with the objective of finding these parameters.

The results of this investigation show that the noise power in the speech interference varies approximately as the eighth power of the velocity. The fact that noise generated from turbulence alone varies as the eighth power of the velocity would indicate that the acoustic power being generated in the jet is due mainly to turbulence. The lower

frequency response indicates a sixth power variation, but since it was not feasible to measure the acoustic power at the extremely low frequencies there are two possible explanation for this result. One is that all the power being generated at the low ranges was not measured because of instrumentation limitations. The other is that since the noise associated with flow past bodies varies as the sixth power of the velocity (6) the predominate noise is generated by the flow past the fins rather than by pure turbulence. A complete investigation of the low frequency response should be made with the objective of finding whether either of the two possibilities is correct.

A more complete and thorough investigation of directivity than was possible in this investigation should be made.

and possible in this investigation should be made.

A more complete and thorough description of diversity than

the one in the previous paper is given, including a description of

either of the two possibilities is correct. The first possibility is

diversity response should be made with the objective of finding whether

rather than by gene frequency. A complete investigation of the two

also (b) the phenomenon which is suggested by the first part of the

associated with this gene problem arises as the study comes to the point

phase of investigation. The idea is that when the data

all the power being generated at the low voltage was not measured for

possible there are two possible explanations for this result. One is that

was found to increase the amount power at the extremely low fre-

frequency response indicated a very great variation, but when it was

APPENDICES

APPENDIX A. INSTRUMENT LIST

1. Hastings Air Meter, Thermocouple Type, Low Velocity Air Meter
2. Altec-Lansing 21-BR-200 microphone, serial no. 4892
3. Altec-Lansing power supply unit, type P-525-A
4. Edison Gauge: Edison Inclined Draft Company, Chicago
5. Magnecorder, type PT6-J
6. General Radio SPL Meter, type 1551-A, modified for cathode follower input
7. General Radio SPL Meter, type 1551-A
8. Telefon Fabrik Automatic A/S and Kobenhaven Filter (1/3 Octave Band) No. 11203-4
9. General Radio Calibrator, type 1307-A
10. General Radio Octave Band Analyzer, type 1550-A

APPENDIX B. DATA

Calibration Data

a. Systems

The system was calibrated with a General Radio type B07-A calibrator by applying a 400 cycle per second tone of 100 db re = $0.0002 \text{ dynes/cm}^2$ at the condenser microphone. All other component calibration is relative to 400 cps. Frequent checks of calibration were made during the period of taking data to insure that excessive drift had not resulted.

b. Amplifier Response

Amplifier response is flat to within less than $\pm 1/2$ db in the range of interest as is also the General Radio sound pressure level meter being used.

APPENDIX B. DATA

Calibration Data

A. Systems

The system was calibrated with a General Radio Type 207-A millivoltmeter by applying a 400 cycle per second tone of 100 db to a 0.0002 dyne/cm² at the condenser microphone. All other components calibration is relative to 400 cps. Frequency errors of calibration were made during the period of testing data to insure that excessive drift had not resulted.

B. Amplifier Response

Amplifier response is flat to within less than $\pm 1\frac{1}{2}$ db in the range of interest as is also the General Radio sound pressure level meter being used.

c. One-Third Octave Filter Calibration (10,000 tap)

Band Number	Band Center Frequency	Band Bounding Frequencies	Band Level Correction
1	50	45- 57	-4
2	63	57- 71	-3
3	80	71- 90	-2
4	100	90- 114	-2
5	125	114- 142	0
6	160	142- 180	0
7	200	180- 228	0
8	250	228- 284	0
9	320	284- 360	0
10	400	360- 456	0
11	500	456- 568	0
12	630	568- 720	0
13	800	720- 912	0
14	1000	912- 1136	0
15	1250	1136- 1440	0
16	1600	1440- 1824	0
17	2000	1824- 2272	0
18	2500	2272- 2880	0
19	3200	2880- 3648	0
20	4000	3648- 4544	0
21	5000	4544- 5760	0
22	6300	5760- 7296	-1
23	8000	7296- 9088	-1
24	10,000	9088-11520	-2

Band Number	Band Frequency	Band Wavelength	Band Frequency
1	10000	10000	10000
2	10000	10000	10000
3	10000	10000	10000
4	10000	10000	10000
5	10000	10000	10000
6	10000	10000	10000
7	10000	10000	10000
8	10000	10000	10000
9	10000	10000	10000
10	10000	10000	10000
11	10000	10000	10000
12	10000	10000	10000
13	10000	10000	10000
14	10000	10000	10000
15	10000	10000	10000
16	10000	10000	10000
17	10000	10000	10000
18	10000	10000	10000
19	10000	10000	10000
20	10000	10000	10000
21	10000	10000	10000
22	10000	10000	10000
23	10000	10000	10000
24	10000	10000	10000

d. Effect of Windscreen on Sensitivity of Microphone

Band Number	Band Center Frequency	Band Level Correction
1	50	0
2	63	0
3	80	0
4	100	0
5	125	0
6	160	0
7	200	0
8	250	0
9	320	0
10	400	0
11	500	0
12	630	0
13	800	0
14	1000	0
15	1250	0
16	1600	-0
17	2000	-1
18	2500	-2
19	3200	-2
20	4000	-2
21	5000	-3
22	6300	-3
23	8000	-2
24	10,000	-4

4. Table of Frequencies of Occurrence of Alleles

Allele Number	Gene Frequency	Gene Frequency
1	0.00	0.00
2	0.00	0.00
3	0.00	0.00
4	0.00	0.00
5	0.00	0.00
6	0.00	0.00
7	0.00	0.00
8	0.00	0.00
9	0.00	0.00
10	0.00	0.00
11	0.00	0.00
12	0.00	0.00
13	0.00	0.00
14	0.00	0.00
15	0.00	0.00
16	0.00	0.00
17	0.00	0.00
18	0.00	0.00
19	0.00	0.00
20	0.00	0.00
21	0.00	0.00
22	0.00	0.00
23	0.00	0.00
24	0.00	0.00

e. Microphone Calibration (grazing incidence)

Band Number	Band Center Frequency	Band Level Correction
1	50	0
2	63	0
3	80	0
4	100	0
5	125	0
6	160	0
7	200	0
8	250	0
9	320	0
10	400	0
11	500	0
12	630	0
13	800	0
14	1000	0
15	1250	0
16	1600	0
17	2000	0
18	2500	-1
19	3200	-1
20	4000	-1
21	5000	-1
22	6300	0
23	8000	0
24	10,000	0

f. Self Noise Generated by Windscreen. See Fig. A-1.

g. Calibration of Air-Meter. See Fig. A-2.

4. Microphone Calibration (using weights)

Band Number	Band Center Frequency	Band Level Correction
1	50	0
2	63	0
3	80	0
4	100	0
5	125	0
6	160	0
7	200	0
8	250	0
9	320	0
10	400	0
11	500	0
12	630	0
13	800	0
14	1000	0
15	1250	0
16	1600	0
17	2000	0
18	2500	-1
19	3200	-1
20	4000	-1
21	5000	-1
22	6300	0
23	8000	0
24	10,000	0

1. Bolt Noise Generated by Windscreen. See Fig. A-1.

g. Calibration of Air-Meter. See Fig. A-2.

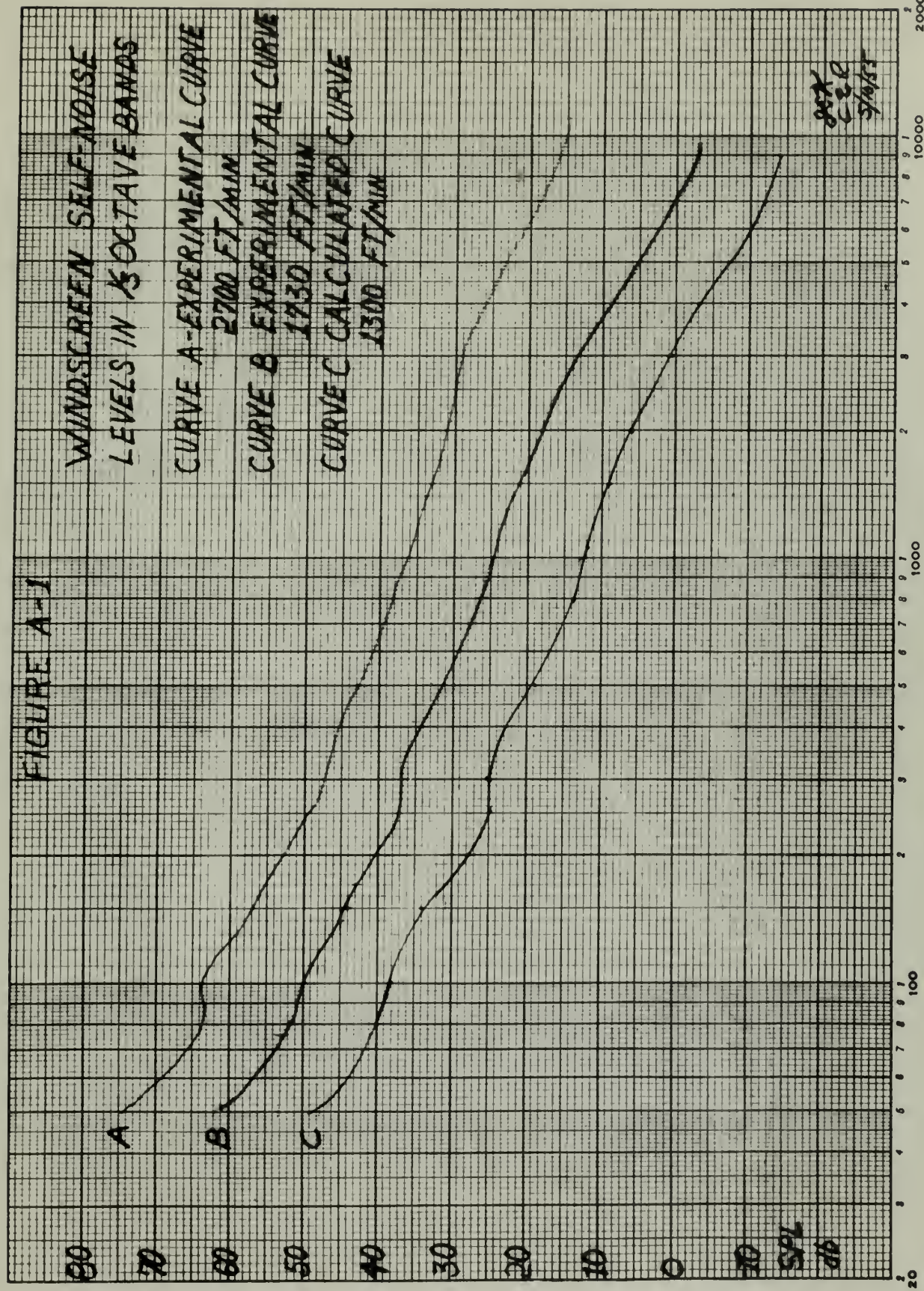
FIGURE A-1

WINDSCREEN SELF-NOISE
LEVELS IN 1/3 OCTAVE BANDS

CURVE A - EXPERIMENTAL CURVE
2700 FT/MIN

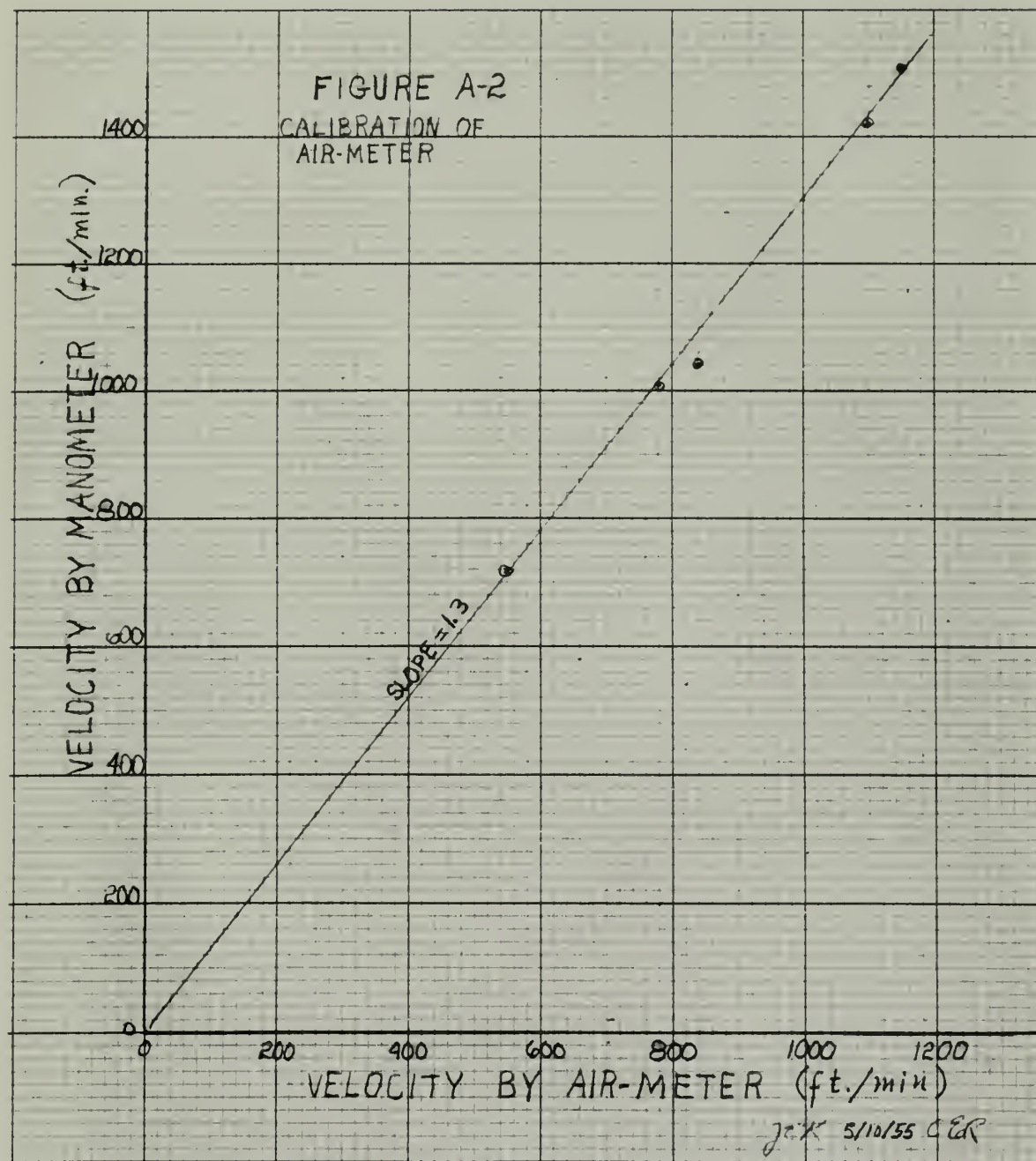
CURVE B - EXPERIMENTAL CURVE
1930 FT/MIN

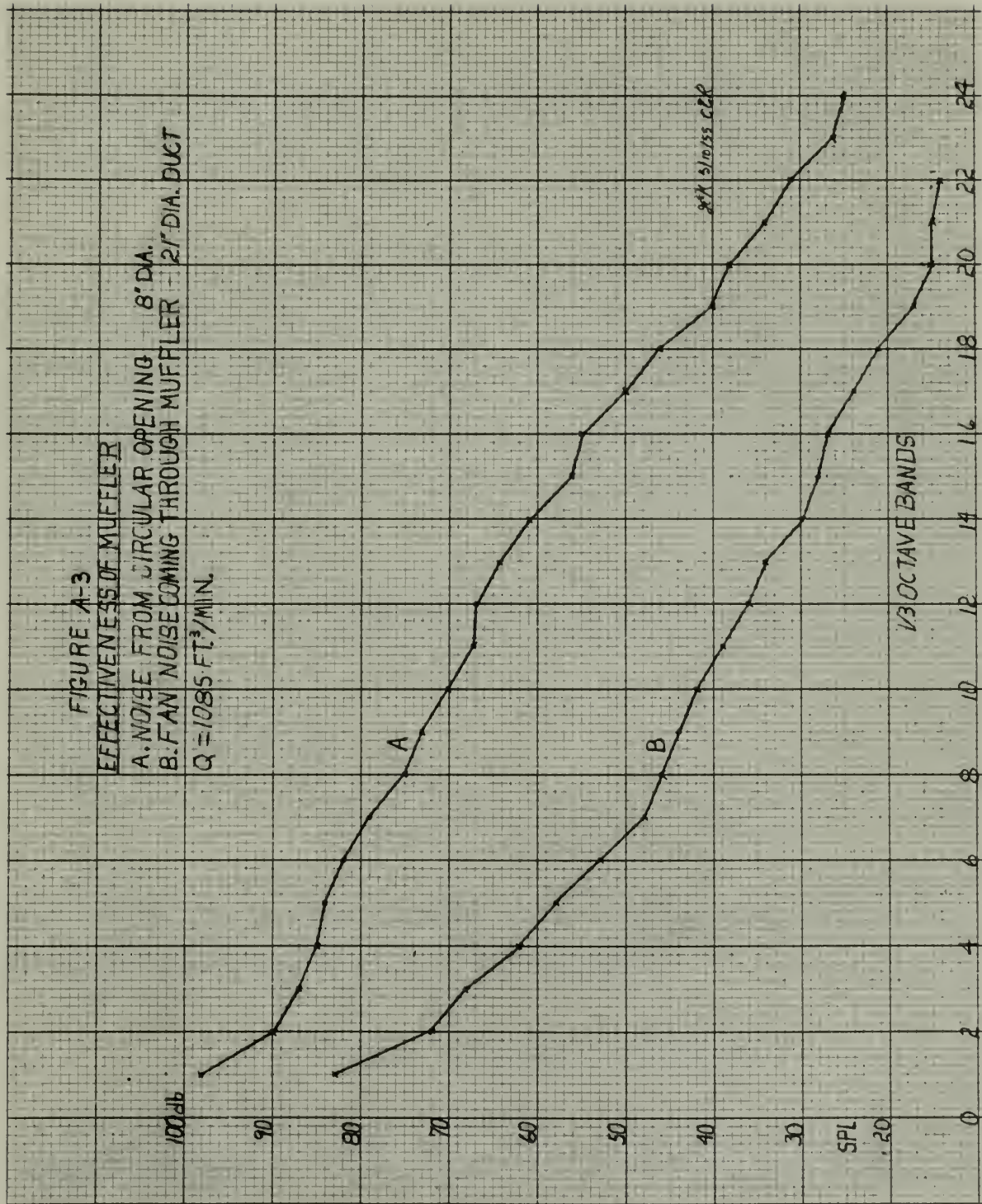
CURVE C - CALCULATED CURVE
1300 FT/MIN



FREQUENCY IN CYCLES PER SECOND

FIGURE A-2
CALIBRATION OF
AIR-METER





- h. Effectiveness of Sinusoidal Muffler in Isolating Fan Noise from Test Section. See Fig. A-3.**

B. *Elasmobranchs of the Atlantic Ocean in the Gulf of Mexico*
from Texas to Florida. See Vol. 4-5.

APPENDIX C. CALCULATIONS

a. PWL

The PWL proceeding down the measuring duct to the exponential horn is given approximately by

$$PWL = SPL + 10 \log_{10} S$$

where the definitions of the symbols are as given in Chapter III. This expression assumes normal atmospheric conditions of temperature and pressure and that the sound pressure level is uniform across the duct. The area of the duct at the point of SPL measurement was 2.4 ft^2 . Therefore,

$$PWL = SPL + 10 \log_{10} 2.4$$

b. Calculation of PWL_{SIL}

$$PWL_{SIL} = SIL_{(2.4 \text{ ft}^2)} + 10 \log_{10} S$$

where S is the area in square feet over which the given SIL exists. The value of S at this point was 2.4 ft^2 . Therefore:

$$PWL_{SIL} = SIL_{(2.4 \text{ ft}^2)} + 10 \log 2.4$$

c. Calculation of Q

$$Q = V_1 A_1$$

APPENDIX II: CALCULATIONS

a. PWL

The PWL preceding gave the measured data to the exponential form is given approximately by

$$\text{PWL} = 37.1 + 10 \log_{10} 2$$

where the definition of the symbols are as given in Chapter III. This expression assumes certain atmospheric conditions of temperature and pressure and that the sound pressure level is uniform across the duct. The area of the duct at the point of SPL measurement was 2.4 ft^2 . Therefore,

$$\text{PWL} = 37.1 + 10 \log_{10} 2.4$$

b. Calculation of PWL_{SIL}

$$\text{PWL}_{\text{SIL}} = \text{SIL}(2.4 \text{ ft}^2) + 10 \log_{10} 2$$

where SIL is the area in square feet over which the given PWL exists. The value of SIL at this point was 2.4 ft^2 . Therefore,

$$\text{PWL}_{\text{SIL}} = \text{SIL}(2.4 \text{ ft}^2) + 10 \log_{10} 2.4$$

c. Calculation of \bar{Q}

$$\bar{Q} = \frac{1}{2} A_1$$

where V_1 and A_1 are the average velocity and area respectively in the air measurement section. Since $A_1 = 2.4 \text{ ft}^2$ at measurement section then

$$Q = V_1 \times 2.4$$

$$Q(\text{c fm}) = 2.4 V_1(\text{f pm})$$

where V_1 and V_2 are the average velocity and the velocity of the air measurement section. Since $V_1 = 5.4 \text{ m/s}$ at measurement section then

$$V_1 = 5.4 \text{ m/s}$$

$$Q = (V_1 A_1) = (5.4 \text{ m/s}) (0.01 \text{ m}^2)$$

$$Q = 0.054 \text{ m}^3/\text{s}$$

From the continuity equation, the flow rate at section 2 is equal to the flow rate at section 1. Therefore, the flow rate at section 2 is also $0.054 \text{ m}^3/\text{s}$. The area at section 2 is 0.01 m^2 . Therefore, the velocity at section 2 is 5.4 m/s .

$$V_2 = 5.4 \text{ m/s}$$

$$Q = (V_2 A_2) = (5.4 \text{ m/s}) (0.01 \text{ m}^2)$$

$$Q = 0.054 \text{ m}^3/\text{s}$$

From the continuity equation, the flow rate at section 3 is equal to the flow rate at section 1. Therefore, the flow rate at section 3 is also $0.054 \text{ m}^3/\text{s}$.

$$Q = (V_3 A_3) = (5.4 \text{ m/s}) (0.01 \text{ m}^2)$$

$$Q = 0.054 \text{ m}^3/\text{s}$$

$$Q = 0.054 \text{ m}^3/\text{s}$$

APPENDIX D. BIBLIOGRAPHY

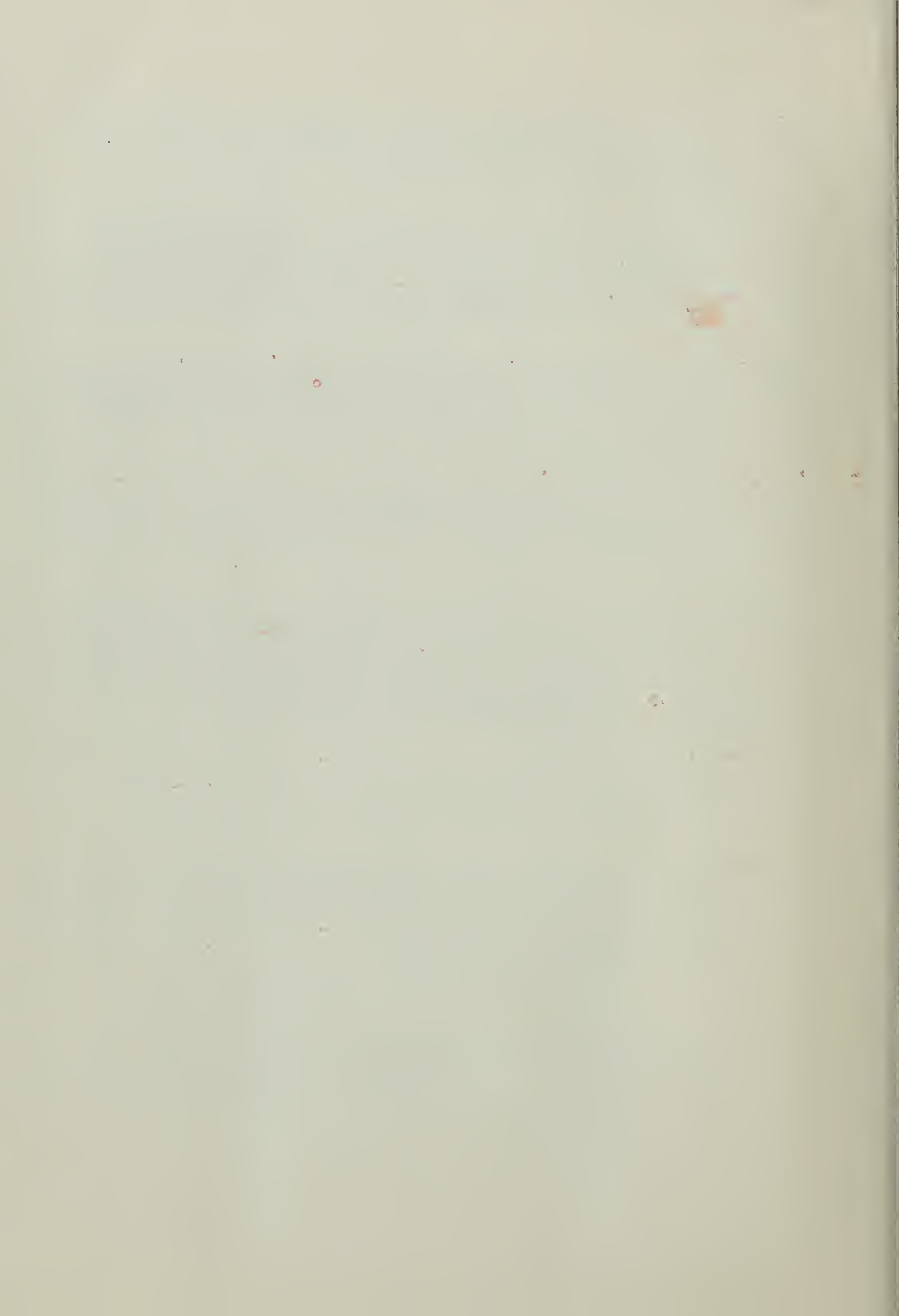
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